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THESIS

ANALYSIS OF AN EMULATED IT-21 LAN OVER A SIMULATED SHIP-TO-SHORE SATELLITE LINK

by

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The Navy's IT-21 philosophy when applied to the Navy-wide Intranet poses a significant problem: how to best adapt to the requirements of the new standard and still make the most of the currently installed network. The integration of Asynchronous Transfer Mode (ATM) backbone and desktop networks with legacy equipment and applications is considered in this thesis. The most current solution to this dilemma is the use of Local Area Network Emulation (LANE). The focus of this thesis is the implementation of LANE over a simulated ship-to-shore satellite link. Data throughput is monitored and analyzed to determine the optimum configuration. Testing is conducted to examine the advantages of routed Emulated Local Area Networks (ELANs) and non-routed ELANs. An inport scenario that benchmarks the two ELAN configurations against the Ethernet Virtual LANs (VLANs) is discussed.

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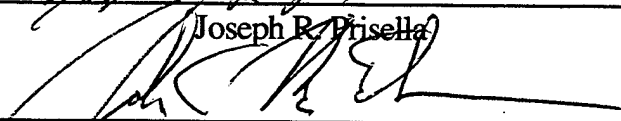## MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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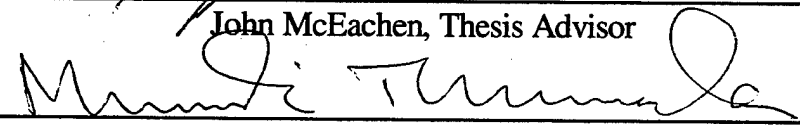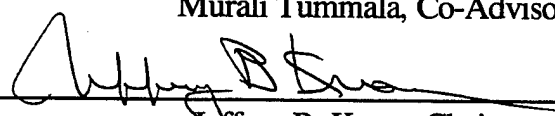
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ABSTRACT

The Navy's IT-21 philosophy when applied to the Navy-wide Intranet poses a significant problem: how to best adapt to the requirements of the new standard and still make the most of the currently installed network. The integration of Asynchronous Transfer Mode (ATM) backbone and desktop networks with legacy equipment and applications is considered in this thesis. The most current solution to this dilemma is the use of Local Area Network Emulation (LANE). The focus of this thesis is the implementation of LANE over a simulated ship-to-shore satellite link. Data throughput is monitored and analyzed to determine the optimum configuration. Testing is conducted to examine the advantages of routed Emulated Local Area Networks (ELANs) and non-routed ELANs. An inport scenario that benchmarks the two ELAN configurations against the Ethernet Virtual LANs (VLANs) is discussed.

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ACRONYMS AND ABBREVIATIONS

ATM   Asynchronous Transfer Mode

BUS   Broadcast and Unknown Server

DG   Default Gateway

ELAN   Emulated Local Area Network

ILMI   Interim Local Management Interface

IS   Information Systems

IT-21   Technology for the 21st Century

LANE   Local Area Network Emulation

LE_ARP   LAN Emulation Address Resolution Protocol

LEC   LAN Emulation Client

LECS   LAN Emulation Configuration Server

LEH   LAN Emulation Header

LES   LAN Emulation Server

LoS   Line-of-Sight

MAC   Medium Access Control

NIC   Network Interface Card

NM   Netmask

NSAP   Network Service Access Point

OSI   Open Systems Interconnection

PVC   Permanent Virtual Circuit

QoS   Quality of Service

RIP-2   Routing Information Protocol Version 2

RRAS   Routing and Remote Access Service

SNMP   Simple Network Management Protocol

SVC   Switched Virtual Circuit

VCC   Virtual Channel Connection

VLAN   Virtual LAN

WAN   Wide Area Network

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I. INTRODUCTION

On March 3, 1997, the U.S. Navy promulgated a policy called Information Technology for the 21st Century, or IT-21 [1], which stipulated the minimum hardware and software requirements for Department of the Navy (DON) Information Systems (IS). IT-21 was intended to standardize DON-wide IS development, and adherence to the policy's guidelines have been implemented. Each component of the prototype system of this thesis currently meets the IT-21 specification with the exception that the host PC's do not have dual PCMCIA/PC card readers. This criterion has no impact on the findings reported in the thesis.

IT-21 mandates that ATM backbones be utilized within LANs connected throughout the Navy (see Appendix A. Section 7. A). It also mandates the minimum standards requirements for software (see Appendix A. Section 7. B). Since current legacy software is designed for connectionless networking, a dilemma arises. This dilemma and the current solution are the focus of this thesis.

A.   THESIS OBJECTIVE

The objective of this thesis is to design, develop, test and analyze an Emulated Local Area Network (ELAN) system. The goal is to document the results of data throughput across a simulated ship-to-shore ELAN. Designing such a system serves three primary purposes:

1. Establishment of a working ELAN system within NPS' Advanced Networking Laboratory.
2. Determination of data throughput for various network designs.
3. Identification of an optimal network configuration, which provides the best throughput given numerous operational scenarios.

B.   THESIS ORGANIZATION

This thesis is organized as follows. Chapter II briefly discusses the terms and basic building blocks of an ELAN. Discussion includes advantages of using an ATM backbone, reasons for LAN emulation (LANE), LANE components, and establishing a call set up

using LANE. Using the OSI model, Chapter III presents two simulation models used in testing. Each model is created using OC-3 ELANs. A separate legacy 100 Mbps Fast Ethernet Virtual LAN (VLAN), is also used to establish benchmark throughput calculations.

Results of data throughput over ATM and 100 Mbps Fast Ethernet networks with results plotted under various conditions are reported in Chapter IV. The throughput calculations simulate both an "inport" and two "underway" scenarios. Throughput observations of the underway scenarios are compared. Several trials are conducted using numerous values for propagation delay, thus simulating various communication link possibilities. Chapter V presents conclusions of the work and suggestions for future studies.

The introduction to the concept of IT-21 is presented in Appendix A. Appendix B contains the LAN Emulation Configuration Server configuration file used in creating the network setup. A detailed ELAN configuration for all attached LAN Emulation Clients and Servers is documented in Appendix C. All raw data used to present the plots contained in Appendix E and F are included in Appendix D. Appendix E details the plots used to analyze the inport scenario testing while Appendix F displays plots for critical underway scenarios.

II. LANE BASICS AND CALL ESTABLISHMENT

A. BACKGROUND

The majority of enterprise market share at the time of deciding which protocols LANE would emulate was determined to be Ethernet/IEEE 802.3 and Token Ring/IEEE 802.5 LANs. [2] With increases in demand for bandwidth to transfer voice, video and data traffic, these technologies are reaching their useful limits. Legacy style networks, such as Token Ring and Ethernet, are broadcast oriented in nature. MAC addresses are used to differentiate one location from another. Only the destination device with the correct MAC address will process the incoming information. Processing slows as the demand for network resources, such as server access and transfers, increases; therefore, a new technology is needed to help support larger broadband networks. ATM offers an extremely high bandwidth alternative. Further, LANE can be implemented at specific points of Ethernet congestion. Use of an edge device, discussed in detail in section C, prevents having to replace segments of the Ethernet topology within a given LAN. [3]

B. ADVANTAGES OF USING AN ATM BACKBONE

The use of ATM provides a more efficient data flow of information among various networks. ATM is well suited for high data rate networks with better resource utilization due to statistical multiplexing of information. ATM also guarantees "Quality of Service (QoS)" for real- time and non-real-time services. Salient features of ATM are listed in Table 1.

Operating speeds available:	1.54, 6.3, 25.6, 44.7, 51.8, 100, 155.5 and 622 Mbps with full duplex capability.
Media access method:	Signaling
Architecture:	Switched
Topology:	Star
Cable:	UTP Category 3, 4 and 5; STP; fiber
Distance:	Copper-100 m; fiber-2 Km
Devices supported:	Adapters, hubs, routers, switches, multiplexers and analyzers
Latency:	Fixed

Table 1. ATM Basic Characteristics. [4]

C. REASONS FOR LANE

ATM is a non-broadcast, connection-oriented technology, which operates quite differently from existing, broadcast, connectionless LANs, such as Ethernet and Token Ring. With the standards set forth in IT-21, we are driven to use some type of interface between these two different technologies. From the ATM Forum: "The goal of LAN Emulation is to present the illusion that one or more ATM ports can be treated as one or more 802.x LAN ports." [5] LANE is the driver software that allows existing application software to connect to the ATM protocol. Existing LANs differ from those of ATM in the following areas:

1. The messages may be characterized as connectionless versus the connection-oriented approach of ATM.

2. Broadcast and multicast are easily accomplished through the shared medium of a LAN.

The LANE service enables end systems (i.e., workstations, servers, bridges, etc.) to connect to the ATM network while the software applications interact as if they are attached to a traditional LAN. Also, this service supports interconnection of ATM networks with traditional LANs by means of bridging methods. This allows interoperability between software applications residing on ATM-emulated end systems and on traditional LAN end systems.

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The LANE service has proven to be important to the acceptance of ATM since it provides a simple and easy means for running existing LAN applications in the ATM environment. Networking customers demand coexistence between legacy networks and higher bandwidth ATM networks. Current uses of ATM include workgroup LANs and LAN backbones. Customers expect to continue to use existing LAN applications as they migrate to ATM.

1. LANE and ELAN

LANE is driver software that imitates LAN services across ATM using ELANs. LANE emulates the services of existing LANs across an ATM network. LANE can be supported via the software layer in end systems. LANE's purpose is not to replace existing LANs but to bridge the gap for ATM simulating a token ring or Ethernet network where higher bandwidth is required. LANE works at the data link layer, level two, of the OSI model as will be discussed in detail in Chapter III. The network layer uses LANE to connect to the ATM's adaptation layer as shown in Figure 1.
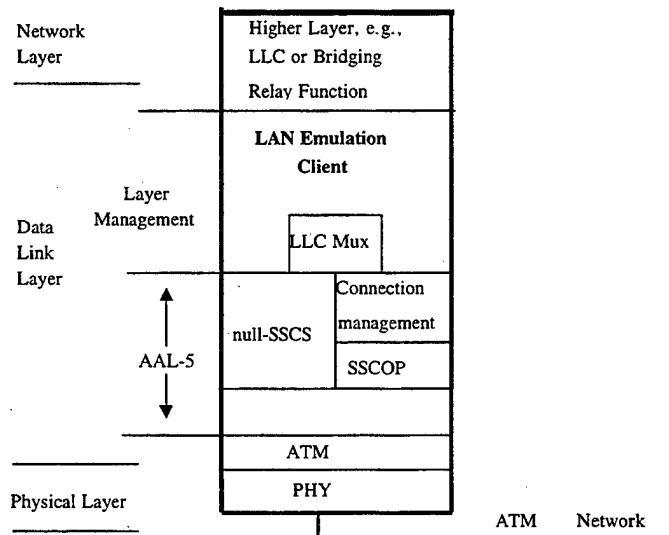
Figure 1. LANE Functioning Within the OSI Model. [6]

With LANE operating at layer two, it is designed specifically to separate the ATM adaptation layer from the network layer. Thus, all interaction between the two is done via the LANE layer "interface." Therefore, the backbone and edge devices are all that need to be replaced when switching to ATM.

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Creating an ELAN allows a group of users to share the same broadcast regardless of whether they are connected to ATM directly or through edge devices. The benefit of this upgrade is the minimal amount of equipment needed to receive the advantages of ATM. Upgrading to ATM does not require total replacement of all network devices and cabling. Since each ELAN operates independently across a single broadcast domain, communication between ELANs requires routing devices. The major components of an ELAN network consist of ATM end systems (i.e., ATM workstations and ATM bridges), each having at least one LANE Client (LEC), and LANE services. We will examine each of these components in the following discussion.

2. LANE Components

a) *LAN Emulation Client (LEC)*

The ATM Forum defines a LEC as follows: "The LEC performs data forwarding and address resolution, provides a MAC level emulated Ethernet/IEEE 802.3 or IEEE 802.5 service interface to higher level software, and implements the LANE User Network Interface (LUNI) interface in order to communicate with other components within a single emulated LAN."[7] Within LANE, host computers with ATM Network Interface Cards (NICs) installed along with appropriate LANE software drivers are referred to as LECs. Edge devices as stated earlier are also referred to as LECs. Use of edge devices prevents having to replace legacy LAN hardware where it is not required. Edge devices use LANE drivers to forward information between an ELAN and an existing Ethernet or Token Ring segment. All LECs regardless of being an edge device or a host, provide data forwarding. They also provide an ATM network service access point (NSAP) address and other ATM control functions.

b) *LAN Emulation Services*

LANE services consist of the following components: the LAN Emulation Server (LES), Broadcast and Unknown Server (BUS), and LAN Emulation Configuration Server (LECS). Together, these three components are responsible for ELAN configuration, address resolution, and broadcast and multicast support.

(1) The LAN Emulation Server. The ATM Forum's definition: "The LAN emulation servers implement the control coordination function for the emulated LAN. The LESs provide a facility for registering and resolving unicast and multicast MAC addresses and/or route descriptors to ATM addresses. A LEC is connected to only one LES. A LEC may register LAN destinations it represents and/or multicast MAC addresses it wishes to receive with its LES. A LEC will also query its LES when the LEC wishes to resolve a MAC address and/or route descriptor to an ATM address. The LES will either respond directly to the LEC or forward the query to other clients so they may respond." [7] ATM to ATM address resolution is conducted using a network service access point (NSAP) address. The LES provides the MAC to NSAP address resolution for each member of the local ELAN. LES software can be installed on any device in the ATM network but is normally located within a switch. Each LEC registers its MAC and NSAP addresses with the LES, allowing the LES to perform MAC-to-NSAP address resolution. The LES accepts MAC address queries, translates the MAC addresses into an NSAP address, and responds back to the LEC directly. The LES enables a source LEC to establish a communication path to a destination LEC upon completion of any address resolution issues. [7]

(2) Broadcast and Unknown Server. The broadcast unknown server supports the broadcast messaging within an ATM network. As defined by the ATM Forum, the BUS "handles data sent by LEC to the broadcast MAC address ('FFFFFFFFFFFF'), multicast data, and initial unicast data which are sent by a LEC before the data direct target ATM address has been resolved (before a data direct VCC has been established)." [7]

A LEC sees a single BUS. The multicast server function provided in the BUS is required as part of LANE to provide the connectionless data delivery characteristics of a shared network to LECs. The main tasks of the BUS are to distribute data with multicast MAC addresses and to deliver initial unicast data, where the MAC address has not yet been resolved to a direct ATM connection. All broadcast, multicast and unknown traffic to and from a LEC passes through this single entity.

A LEC sends data frames to the BUS, which serializes the frames and re-transmits them directly or indirectly to other LECs.

The BUS implementation may have multiple interfaces, which support receiving and forwarding of specific multicast MAC addressed frames over multiple VCCs. If a LEC does not need to receive all multicast MAC addressed frames, it may inform the LES during initialization. The LES may then selectively forward multicast MAC addressed frames to only those LECs that requested them.

It is standard practice to co-locate the LES and BUS, creating what is known as an "intelligent BUS." The advantage of the intelligent BUS is that the BUS takes advantage of the LES address table and routes traffic only to the destination LEC. This implementation reduces undesired broadcast traffic and increases efficiency. [7]

(3) LAN Emulation Configuration Server (LECS). A LECS supports the configuration of large broadband networks by assigning each LEC to one or more specific ELANs. As defined by the ATM Forum, a LECS "assigns individual LECs to different emulated LANs. Based upon its own policies, configuration database and information provided by LEC and other devices, a LECS assigns any client which requests configuration information to a particular emulated LAN service by giving that client the appropriate LES ATM address. This method supports the ability to assign a client to an emulated LAN based on either the physical location (ATM address) or the identity of a LAN destination, which it is representing. All LECs must be able to obtain information from a LECS using the configuration protocol." [7] The LECS is normally located in an ATM switch along with LES and BUS.

The LECS make configuration assignments based on administrative policies, database information, and physical location based on information provided by a LEC. After determining eligibility, the LECS provides the LEC with the ATM address of their appropriate LES. The LECS maintains a database that contains administrative information for each associated ELAN including ELAN type, application type supported, and LES address by which each requested LEC must register.

The LECs register with the LECS in one of the following three methods. The first method is through a predefined LECS address at the LEC. The second method is through an interim local management interface (ILMI) discovery. ILMI is a standard that specifies the use of SNMP in an ATM management information base

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providing network status and configuration information. The third and final method is through a "well-known" address of the LECS. A "well-known" address is the ATM NSAP address specified by the ATM forum. As discussed earlier, the NSAP address enables LECs to communicate with the LECS and LES.

In order to realize emulated connectionless LAN communication in a connection oriented ATM environment, LANE servers work together to provide address resolution and data forwarding for each attached client.

3. Establishing a Call Up Using LANE

LANE supports both switched virtual circuits (SVCs) and permanent virtual circuits (PVCs). This is completed using ATM Virtual Channel Connections (VCCs). A VCC is a logical connection and is the basic unit of switching within ATM. VCCs are the lowest level of logical paths within ATM networks. Figure 2 illustrates the relationship of VCCs within ATM's connection-oriented environment.
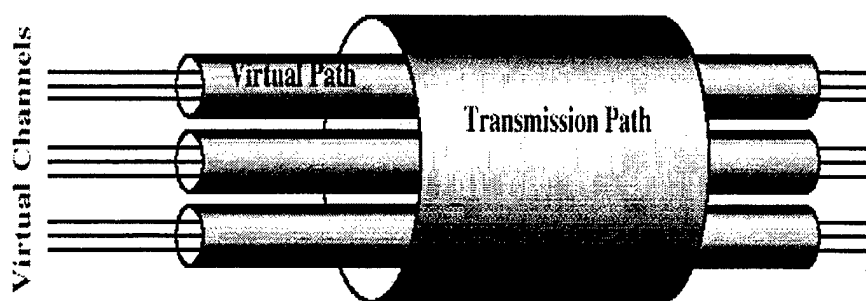
Figure 2. ATM Connection Relationships. [8]

Within LANE, we are concerned primarily with two categories of VCCs: control messaging and data traffic. Figure 3 illustrates the VCC within a simple ELAN, which connects two LECs.
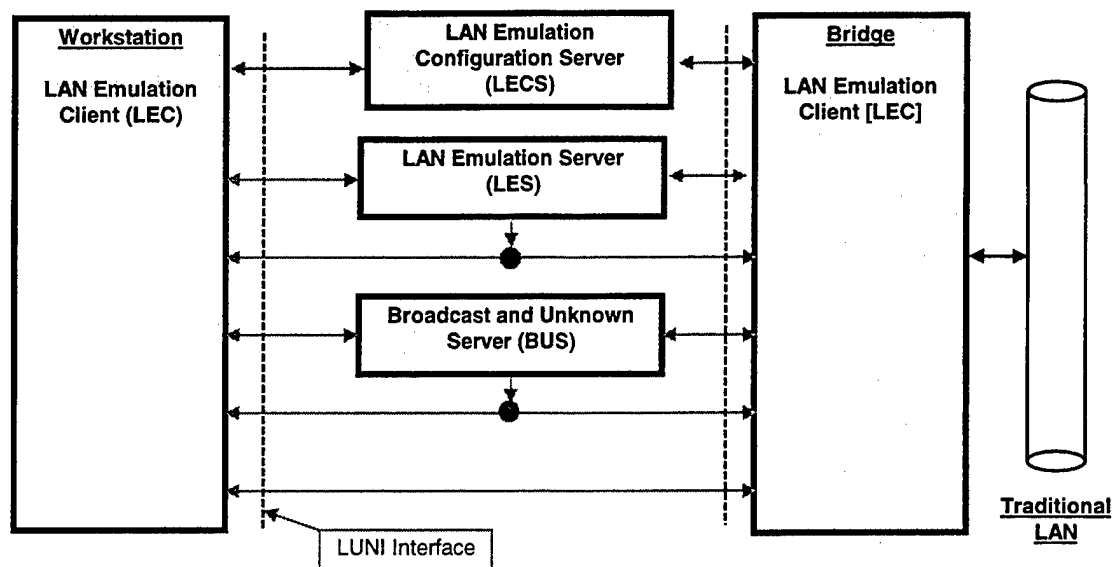
Figure 3. VCC's Connections Within an ELAN. [6]

a) *Control Messaging*

This type of connection is used for control traffic functions: initialization, registration and address resolution. These are briefly described as follows.

1. Initialization involves obtaining the NSAP address of the LES, joining or leaving an ELAN and declaring if a LEC desires to receive LE_ARP requests for any traffic with unregistered destinations.

2. Registration requires furnishing of all applicable MAC addresses a LEC is setup to respond to.

3. Address resolution requests and replies are used to obtain the ATM address associated with LECs with particular MAC addresses.

There are three distinct control message VCCs used in establishing communications of a LEC within an ELAN. The first connection is the LEC to LECS configuration direct VCC. The configuration direct VCC is a bi-directional VCC setup by the LEC as part of the LECS connection phase and is used to obtain configuration information, including the address of the LES [6]. The entity may maintain this VCC while participating in the emulated LAN for further queries to its LECS. The configuration direct VCC may be used to inquire about a LEC other than the one to which the configuration direct VCC is attached. Figure 4 illustrates the connection of the LEC to LECS via the configuration direct VCC.
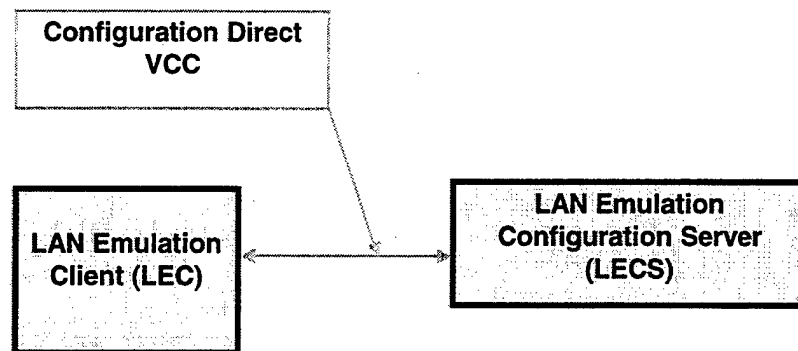
Figure 4. Configuration Direct VCC Between LEC and LECS. [6]

The second connection established is the control direct VCC. The purpose of this VCC is to maintain communications between the LEC and LES throughout the period during which the LEC is a member of the ELAN. This VCC is established during the initialization stage when the LEC joins the ELAN. The control direct VCC is a bi-directional point-to-point flow to the LES for sending control traffic. The LEC is required to accept control traffic from this flow.

The final control messaging VCC is the control distribute VCC. The ATM Forum defines the control distribute VCC as an optional unidirectional point-to-multipoint VCC [6]. This VCC is used to distribute control traffic to the LEC. The control distribute VCC is normally setup during the initialization phase by the LES. If a setup is directed by the LES, the LEC is required to accept the control distribute VCC prior to acceptance into the ELAN. Once established, the call must be maintained throughout the entire ELAN connection of the attached LEC. Figure 5 illustrates the VCCs functioning between the LEC and LES.
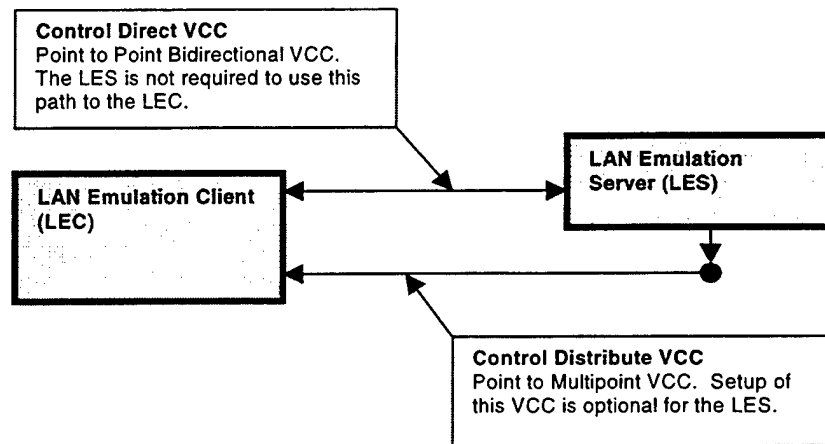
Figure 5. LEC to LES Control Messaging VCCs. [6]

b)   Data Traffic Messaging

The second group of VCCs is the data traffic (channel) VCCs. There are three types of data connection: multicast send, multicast forward, and data direct [6].

The purpose of the multicast send VCC, once established between the source LEC and the BUS, is to allow the LEC to transfer multicast traffic to the BUS. In return, the BUS uses the channel to send data to the LEC. Upon initial call establishment between two LECs the multicast send VCC is used to transfer unicast data while the source LEC awaits the LE_ARP reply from the LES. The multicast send VCC is a bi-directional, point-point VCC that is maintained throughout the ELAN connection.

The multicast forward VCC is established immediately following the multicast send VCC. The multicast forward VCC is used by the BUS to transfer data to the attached LECs. The multicast forward VCC is either point-to-multipoint or unidirectional point-to-point. This VCC is established at ELAN setup and is functional prior to allowing the LEC to transfer data within the ELAN. The use of the multicast forward and multicast send VCCs makes ATM more efficient in that data does not have to wait for a complete connection to be obtained before data is actually transferred within the ELAN. The bus forwards the unknown traffic to all registered LECs within the ELAN using multicast forward VCC's. Like the multicast send VCC, this connection is active throughout the period in which a LEC is connected to the ELAN. Figure 6 illustrates the connection of both the multicast send and multicast forward VCCs between the LEC and BUS.

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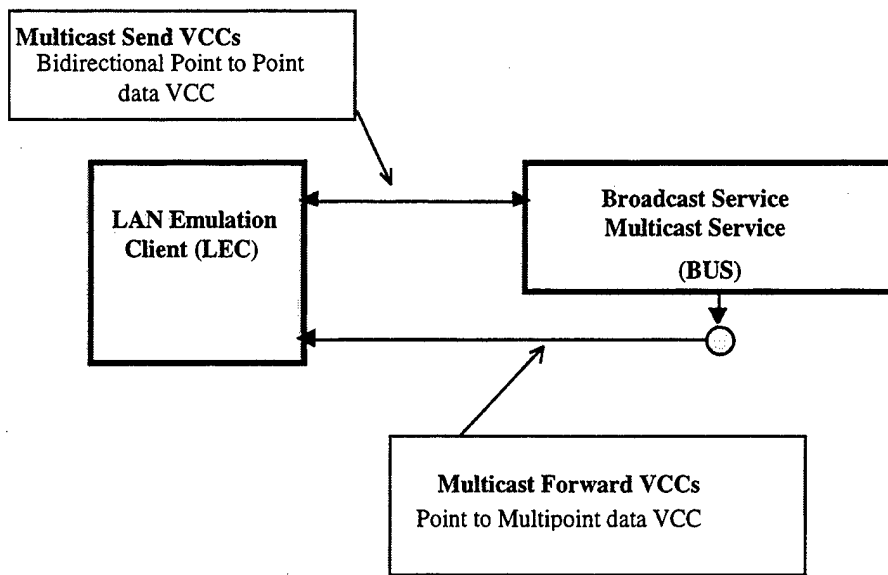
Figure 6. LANE LEC/ BUS Multicast VCC. [6]

The final data traffic VCC is the data direct VCC. The data direct VCC is used to transfer unicast traffic between a source and destination pair of LECs. This VCC is established upon receipt of the LE_ARP reply message from the LES, which holds the NSAP address of the destination LEC. Once established, all traffic between the source and destination LECs is done over the data direct VCC. Data direct VCCs are functional for the duration of time required to send data traffic. Figure 7 is an illustration of the data direct VCC between two LECs.
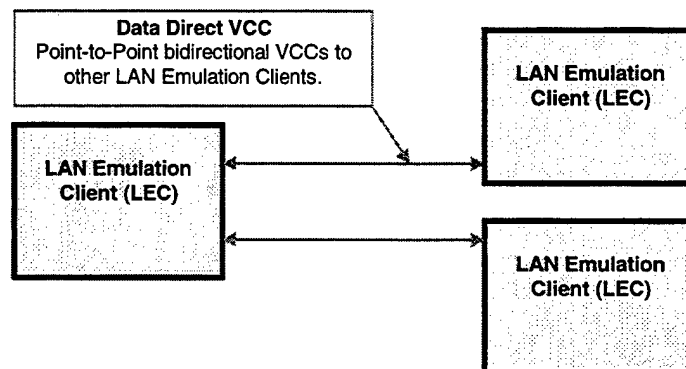
Figure 7. LANE LEC to LEC Data Direct VCC. [6]

Quality of Service is monitored and enforced from the time of establishment to the time of breakdown of the data direct VCC. The multicast traffic within the multicast send and multicast forward VCCs is not monitored with regards to QoS; therefore, there is no guarantee of service at this point in the call establishment.

Understanding the call setup and breakdown is important. Recall that the connection between any two LECs is maintained throughout the duration of the call via the data direct VCC. As more LECs are allowed to enter an ELAN, more data direct VCC's are required to transfer data between stations. Within an ATM network, QoS contracts are negotiated prior to allowing a LEC to participate within the ELAN. Therefore, with limited bandwidth, the number of participating LECs is potentially limited, thus placing a maximum on the number of participants within an ELAN.

With this in mind, this study focused on the throughput capability of two types of ATM WANs. Chapter III demonstrates the model layout used to conduct testing and analysis.

III. ESTABLISHING A SHIP-TO-SHORE SIMULATION MODEL

A.   BASIC BATTLEGROUP WAN STRUCTURE

Figure 8 represents a simple battlegroup representation in which multiple ships and shore stations may participate within a WAN. Various segments of this scenario will be studied in regards to throughput capacities. However, a detailed understanding of the hardware and software requirements incorporated in the creation of an ATM WAN should be understood to assist in network establishment.
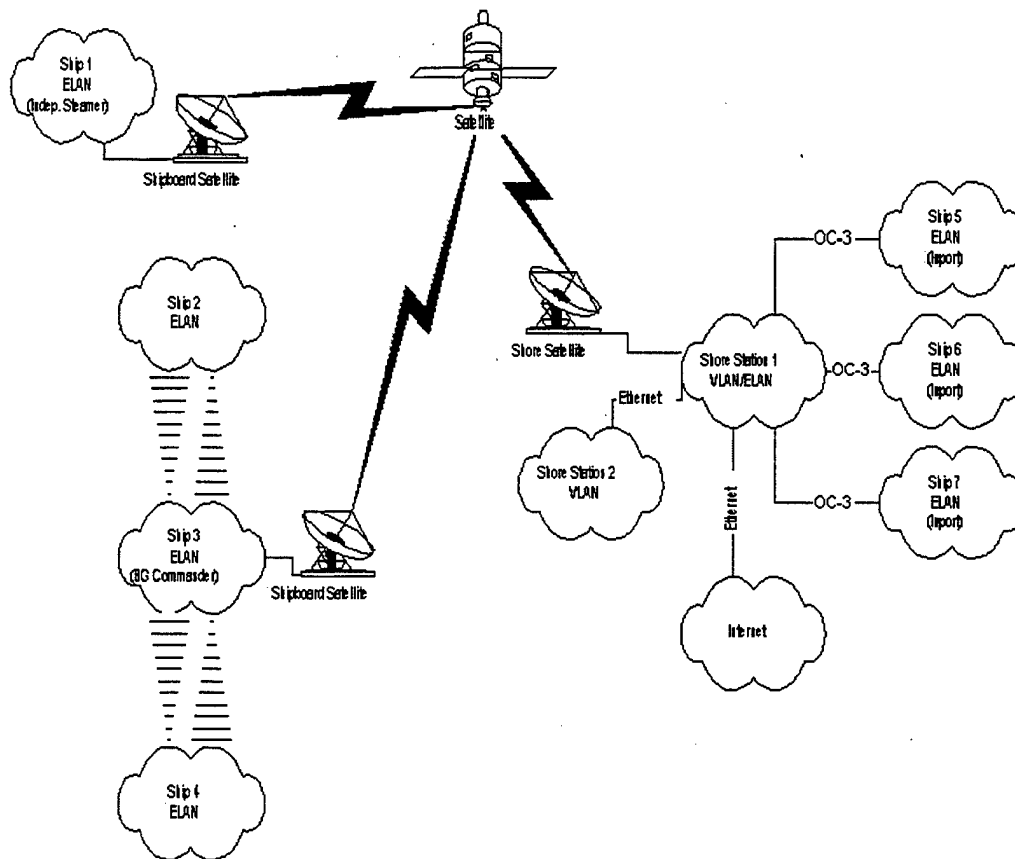
Figure 8. Sample Battlegroup WAN Scenario.

Figure 9 focuses only on the ship-to-shore inport portion described in Figure 8. This cloud diagram represents any number of workstations and servers attached to a scalable WAN environment. Figure 9 is used in Chapter IV to benchmark the OC-3 ATM network to a standard 100 Mbps Fast Ethernet network. The benchmark comparison to Fast Ethernet is calculated only in the zero propagation delay trial as Ethernet was not intended for use over a wide area.
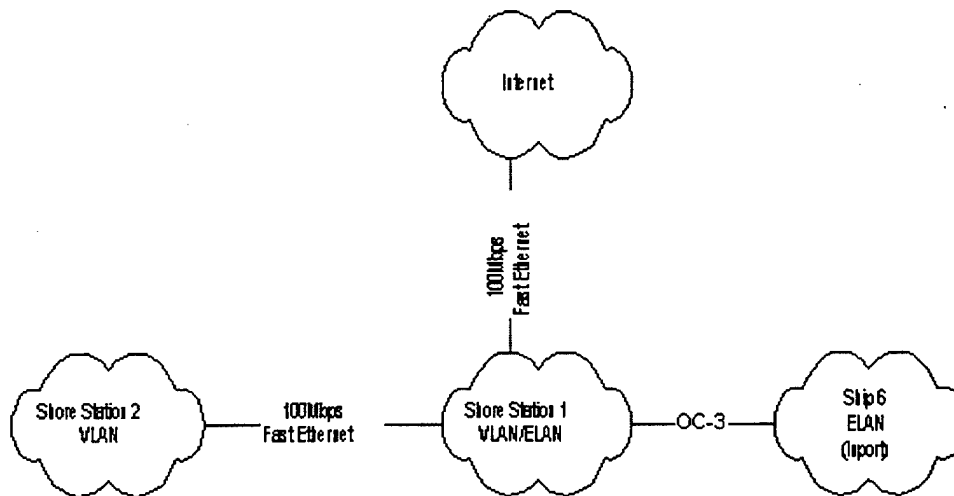
Figure 9. Ship(inport)-to-Shore ATM with Shore-to-Shore Fast Ethernet Connection.

B.   EQUIPMENT SETUP

Equipment setup will be discussed in the context of the physical, data link, and network layers of the OSI model displayed in Figure 10.
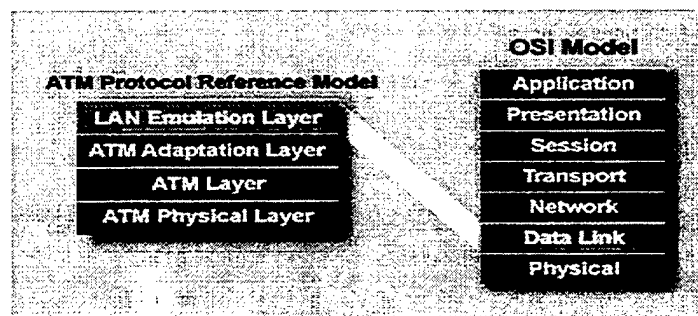
Figure 10. LANE Included OSI Model. [3]

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1. Physical Layer

The physical layer incorporates all hardware required for use in the simulation model. Each of the two domains used similar hardware. The ship domain consists of two workstation PCs. One PC is established as the ship's server/router, and the other is one of what could be many shipboard workstations. The server/router is a Dell Dimension XPS D266 operating with 196 MB RAM. A FORE systems PCA-200E 2.0.1 (PCI bus) network interface card (NIC) is installed for network operation. The workstation is a Dell Dimension XPS H266 operating with 98 MB of RAM with PCA-200E 2.0.1 ATM NIC installed. Both of the PCs are connected to a FORE systems ASX-200BX ATM switch by SC-SC multimode 62.5/125 μm fiber cables. The ASX-200BX utilizes one Intel I960HA processor operating over hardware version F with 16 MB DRAM and 4MB of flash memory.

The shore domain's server/router is a Dell Dimension XPS Pro200n with 128 MB RAM. As within the ship domain, the shore server/router utilizes a FORE systems PCA-200E ATM NIC. Also installed is a 3Com 905B-TX Fast Ethernet NIC used for accessing the Internet and other shore servers. The shore workstation is a Dell Dimension XPS Pro200n operating with 64 MB RAM, and, similar to the ship domain, a FORE PCA-200 ATM NIC is installed. The shore domain PCs are connected to a FORE systems ASX-200BX through the same fiberoptic cabling as used in the ship domain.

The two domains are physically interconnected via the same multimode fiber as discussed above. An Adtech SX-14 data channel simulator is inserted between the most remote member of the shore ELAN and its associated server. The SX-14 is installed with single mode fiber transmit and receiver interface. This presented a unique problem that was overcome through the use of an airgap on the transmit side of the SX-14. The airgap allows for enough attenuation loss between the transmitter laser and the multimode fiber to prevent overdriving and potentially damaging the receiver's photo diode. It is understood that an airgap is a temporary fix; however, it was decided that the cost of upgrading the two ASX-200 BX switches to conclude a long haul or medium haul single mode module was not cost effective at $18000 per module.

Figure 11 is the physical layer simulation model used to demonstrate the single ELAN system. Figure 12 is a layout diagram of the physical layer of the simulation model of a two-ELAN system.
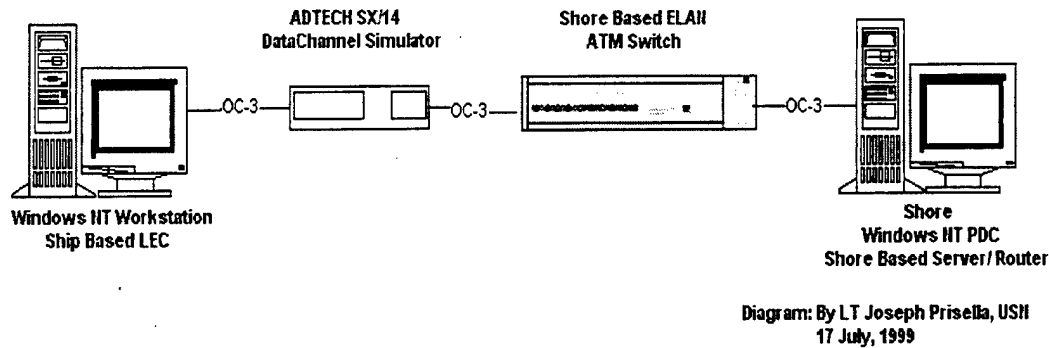
Figure 11. Single ELAN Physical Layer Simulation Model.
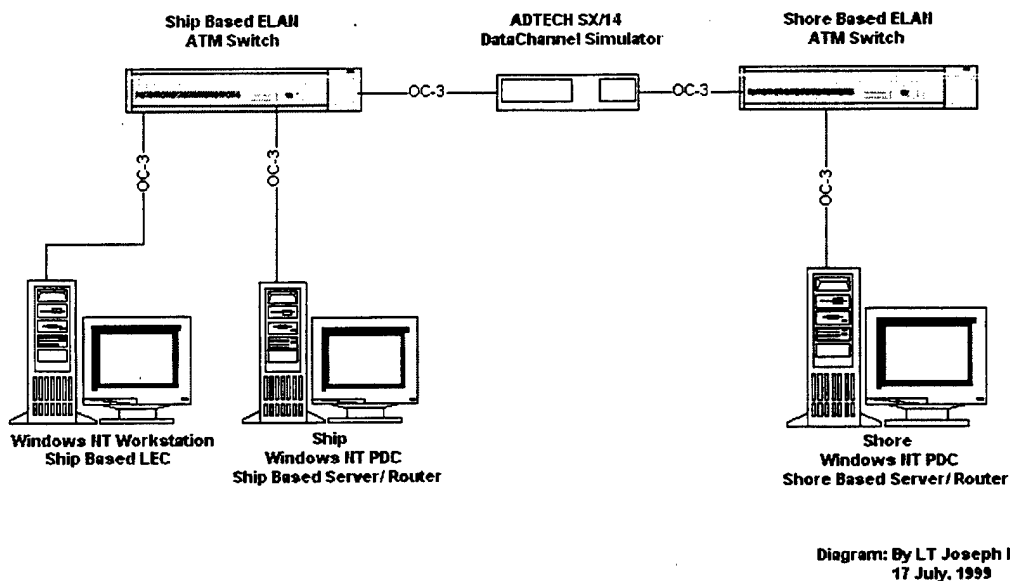
Figure 12. Two ELAN Physical Layer Simulation Model.

2. Data Link Layer

A closer look at Figure 10 reveals that it is in the data link layer of the OSI model where the LAN emulation layer resides. Several key installation areas are attended to in this layer to create the working ELAN environment as in Figure 11 and Figure 12.

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a) *LAN Emulation Server Setup*

The first step in creating an ELAN is configuring the LECS. Appendix B contains the LECS configuration file used within the simulation model. A line by line breakdown of Appendix B is provided to better understand the functionality of the LECS.CFG file. The names of all ELANS that have accept keys must be included in the statement:

Match Ordering: Shore, Ship

This line of code provides the order in which to apply the accept and reject rules to the group.key statement. The groups in the simulation are "shore" and "ship," and the keys are "accept" as denoted by:

shore accept: xx.xxxx.xx.xxxxxx.xxxx.xxxx.xxxx.xxxxxxxxxxxx.xx

ship accept: xx.xxxx.xx.xxxxxx.xxxx.xxxx.xxxx.xxxxxxxxxxxx.xx

where the use of the "don't care" address

xx.xxxx.xx.xxxxxx.xxxx.xxxx.xxxx.xxxxxxxxxxxx.xx

allows for any client to be accepted within an ELAN. The length in bytes of the largest frame is specified by:

Maximum_frame_size: 1516

Frame selection size options are 1516, 4544, 9234, and 18190. The default for Ethernet is 1516 and is therefore used throughout the simulation model.[9] The maximum frame size calculation for Ethernet is based on the maximum of 1518 octets for the DA (6 octets), SA (6 octets), Type/Length (2 octets), Info (1500 octets), and FCS (4 octets) fields. Since LANE data frames also includes the 2 octet LANE Header (LEH) (but does not include the FCS field), the emulated Ethernet maximum frame size is 1516 octets (LEH, DA, SA, Type/Length, and Info fields). This results in 32 ATM cells (48 byte payload per cell) or 1536 octets including 12 octets of padding and the 8 octet trailer for AAL5. [6]

The shore ASX-200 BX ATM switch uses NSAP address:

Shore.Address:

47.0005.80.FFE100.0000.F21A.44A2.0020481A44A2.01

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The same address is also used in the following line of code:

Shore.BUS_Address:

47.0005.80.FFE100.0000.F21A.44A2.0020481A44A2.01

which follows the convention that shore LES and BUS are co-located to create the "intelligent BUS" as discussed in the BUS segment of Chapter II. The final line of code corresponding to the shore ELAN is the

Shore.LAN_Name:shore

which refers to the alias "shore" and is used to associate with the switch NSAP address. The ship ELAN code is nearly identical to the shore ELAN code with the exception of the

Ship.Address: and ship.BUS_Address

fields, which contain the NSAP address of the ship's ASX-200 BX ATM switch:

Ship address:

47.0005.80.FFE100.0000.F21A.3E9A.0020181A3E9A.02

Ship.BUS.Adress:

47.0005.80.FFE100.0000.F21A.3E9A.0020181A3E9A.02

The .LAN_name is modified to

Ship.LAN_name: ship

It should be noted at this point that the last byte (2 characters) is reserved as the selector byte. The shore selector byte has been arbitrarily set to 01, and the ship selector byte has likewise been set to 02. With this LECS configuration file, all LECs wishing to join either ELAN must attempt to establish a VCC to the "well-known" LECS address specified as 47.0079.00.000000.0000.0000.0000.00A03E000001.00 as required by the ATM forum. A special note is that 00A03E forms the ATM Forum assigned Organizational Unit Identifiers (OUI) octet with 000001 having been allocated by the ATM Forum. [7]

The procedure for uploading the LECS.CFG file were followed in accordance with the guidelines for configuring an emulated LAN, outlined in section 3.6.3

of reference [9], for both ASX-200 BX switches. In Step 2 of the installation, the command "configuration Lane LECS new OXOC-2B LECS.CFG" was used by default, providing the switches with the ATM Forum's "well-known" LECS address. Once these steps have been completed, the LANE services are functional and awaiting the LEC installations to complete the data link layer requirement.

b)   LAN Emulation Client Setup

The understanding of the installation of LANE drivers is critical in establishing a LANE environment. There are two parts to the installation of FORE ATM adapter software. The first step is the installation of the ForeRunner ATM adapter software. This software, once loaded, provides several setup options to the administrator. All settings for the simulation model were set to default. It is important to note that the fragment size is set to appropriately 1536 for Ethernet emulation. Figure 13 is the ForeRunner PCA ATM adapter dialog box. Since OC-3 is the means used to connect the NIC to the switch, the "OC3 framing: SONET" and the "empty cell insertion: unassigned" options are selected. If multiple NICs are installed the adapter's identifier will reflect the ATM adapter number.
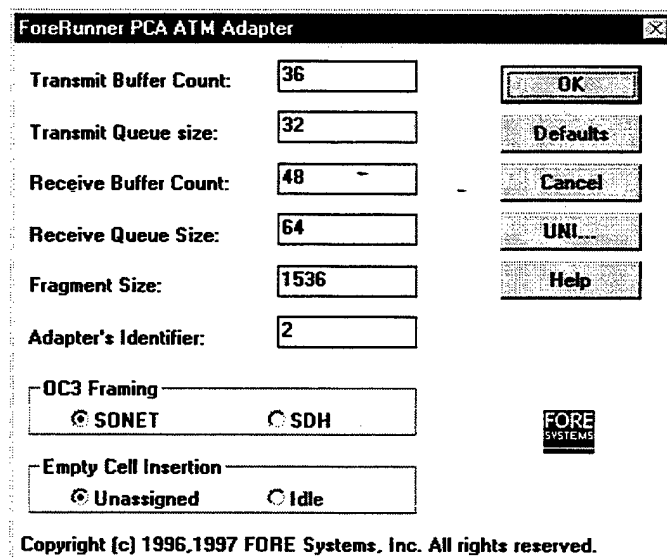
Figure 13. ForeRunner PCA ATM Adapter.

The second step is the loading and configuring of the ELAN adapter drivers. The ELAN LECs are defined in this step. Page 5-10 of reference [10] describes in detail the

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steps taken to complete the installation. Figure 14 is the dialog box display for the ForeRunner emulated LAN adapter. The selections of the values described in Figure 14 are identical for both the ship and shore workstations.

The configuration of the shore server LEC requires ATM to be installed as adapter 2. Adapter number 1 is a standard 3Com 905B-TX 100 Mbps Fast Ethernet adapter used to connect the other VLAN equipment and the Internet.

The ship server/router is unique in its configuration. The capability of the PCA 200-E ATM adapter allows a single adapter card to function over two separate ELANs. With this capability, only one LEC onboard ship needs to participate in both the ship and shore ELANs to provide the shore services to the ship workstations. The only additional step required in establishing the simulation setup is the configuring of the ELAN adapter drivers.
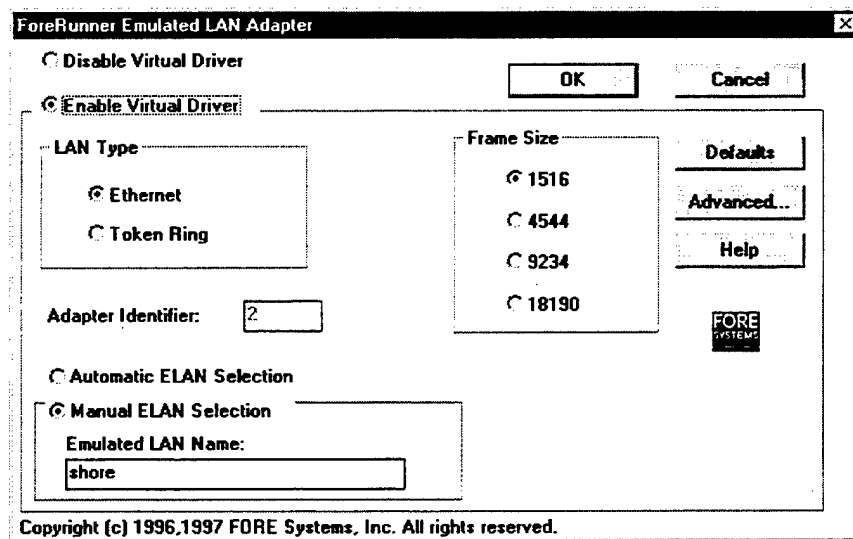
Figure 14. ForeRunner Emulated LAN Adapter.

The ship ELAN server/router needs to have the drivers installed twice with the manual ELAN selection block as displayed in Figure 14 set to "ship" for one of the ELAN adapters and set to "shore" for the other. Figure 15 is the network neighborhood adapter window detailing the adapters installed. Note only one ELAN name is allowed per each ELAN adapter. By issuing the ASX-200BX command:

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configure LANE LEC> new

the switch can be added as a participating LEC within the respective ELAN. Appendix C
describes in detail the following important parameters created during the installation and
configuration of the ship and shore ELANs:

1. ELAN Name.
2. LES and BUS NSAP addresses.
3. The LANE type and maximum packet size.
4. The assigned non-proxy control distribute VCC, proxy control distribute VCC
   and the multicast forward VCC.
5. The number of LECs assigned to the ELAN.
6. Each LEC's NSAP and MAC address and the currently assigned control direct
   VCC.
7. The switches assigned name and NSAP address, which includes the operator
   assigned selector byte used previously when configuring the switch as a member
   of an ELAN.
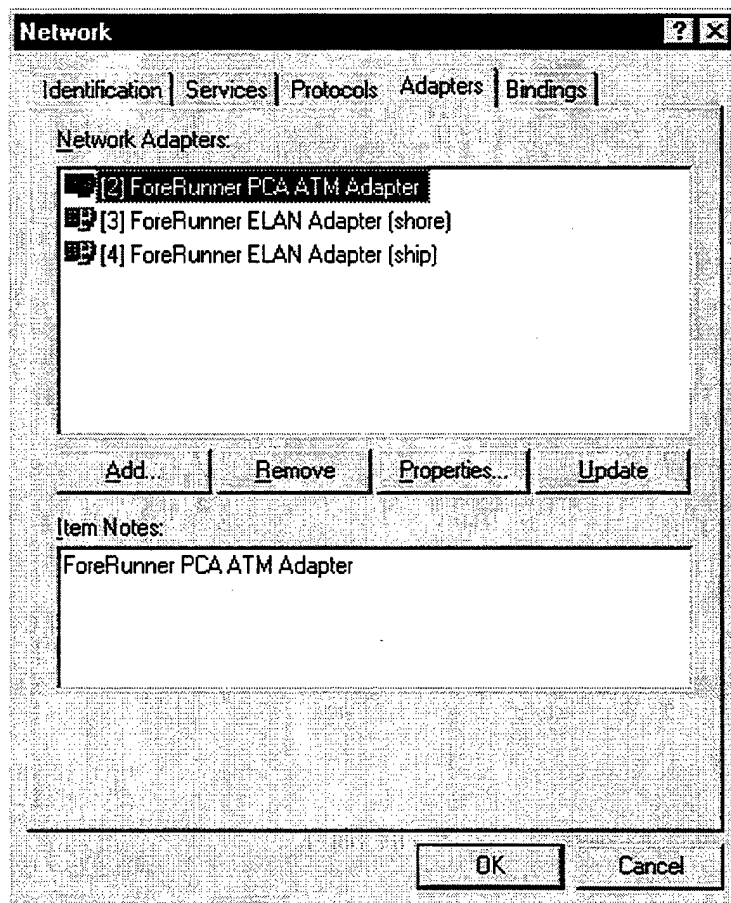
Figure 15. Network Dialog Box for Ship's Server/Router.

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3. The Network Layer

The network layer is the third level in the OSI model. Here we can choose TCP/IP, NETBEUI or IPX/SPX to bind our ELAN [10]. For the simulation model, TCP/IP has been chosen to handle the movement of packets throughout the network. Figure 16 is a diagram detailing the IP addresses, netmasks (NM), and default gateways (DG), used in creating the simulation model.
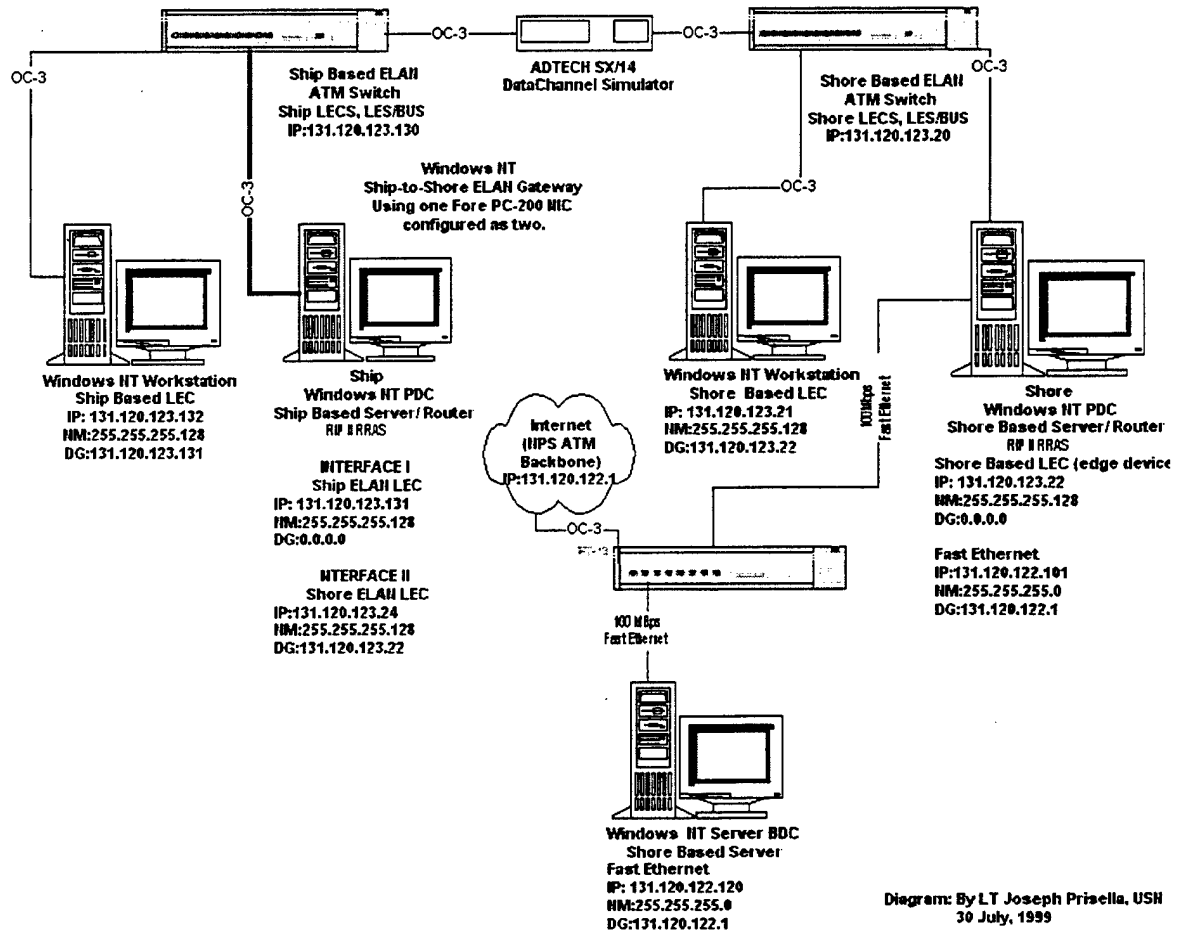
Figure 16. Detailed IP Addressing Including Netmasks and Default Gateways.

All IP addresses in the simulation model begin with 131.120. The Advanced Networking Laboratory has been restricted to the class 'C' level addresses 122.xxx for Ethernet networks and 123.xxx for ATM networks. The information in Figure 16 is applied to each adapter using the TCP/IP properties dialog box within Microsoft Windows NT 4.0. Under the routing tab of the TCP/IP properties dialog box, 'Enable IP forwarding' has been

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selected on both ELAN server and router LECs. With IP forwarding enabled, TCP/IP data packets flow through both server/router edge devices.

Figure 17 is a basic block diagram, which illustrates the IP addressing as implemented in the simulation model.
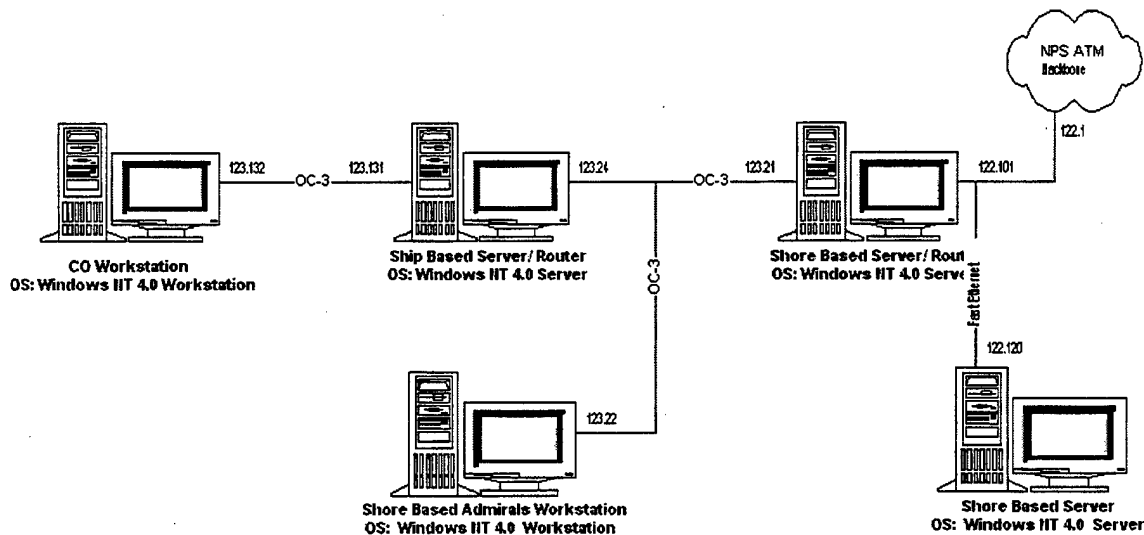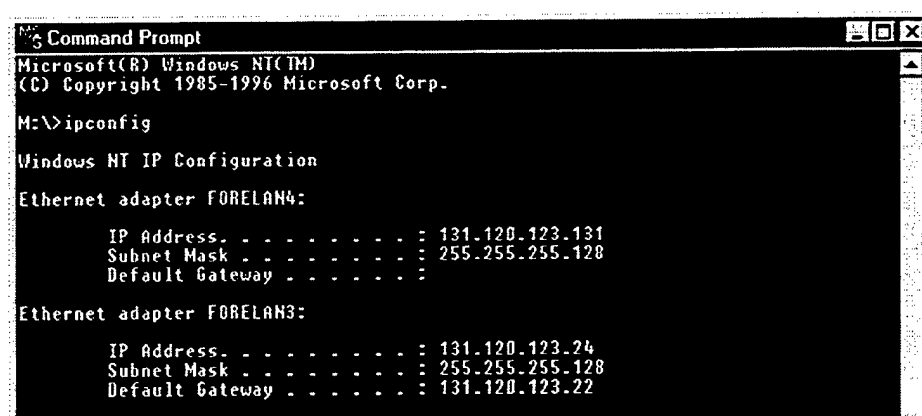
Figure 17. Basic IP Address Block Diagram.

Microsoft's updated Routing and Remote Access Service (RRAS) version 2 software supports Routing Information Protocol version 2 (RIP-2). The key advantage to operating RIP-2 is the ability to further divide class "C" addresses into smaller subnets. RRAS is supported only by Windows NT 4.0 Server. The term server/router is used when discussing the ELAN servers as only servers are designed to support the RIP-2 compliant routing service. The ship's ELAN IP addresses are restricted to the 128 upper class 'C' host addresses through the use of the network mask 255.255.255.128. All devices within the ship's ELAN including the ASX-200BX switch are assigned the IP address range 123.128 to 123.255. The shore's ELAN IP addresses are likewise restricted to using only the lower 128 addresses in the range 123.0 to 123.127, using the same subnet mask. Since the ship's server/router is a member of both the ship and shore ELAN as discussed in the data link

layer section, it is assigned IP addresses corresponding to each subnet. Figure 18 uses the IPConfig command to display the configuration of the ship's server/router.

```
Command Prompt                                    ▁▢▣▨
Microsoft(R) Windows NT(TM)
(C) Copyright 1985-1996 Microsoft Corp.

M:\>ipconfig

Windows NT IP Configuration

Ethernet adapter FORELAN4:

        IP Address. . . . . . . . . : 131.120.123.131
        Subnet Mask . . . . . . . . : 255.255.255.128
        Default Gateway . . . . . . :

Ethernet adapter FORELAN3:

        IP Address. . . . . . . . . : 131.120.123.24
        Subnet Mask . . . . . . . . : 255.255.255.128
        Default Gateway . . . . . . : 131.120.123.22
```

Figure 18. IPConfig of the Ship's Server/Router.

The shore server/router was also upgraded to operate the current RRAS version. The reason for the upgrade differs from that of the ship's server/router. The shore server/router could effectively use RIP-1 to route TCP/IP packets within its domain as the router crosses the 122 and 123 subnets meeting RIP-1 requirements. The reason then lies in the ability to forward TCP/IP packets from the ship's CO's workstation to the internet. In order to accomplish this, all routers along the route must support RIP-2, or no IP packet forwarding can be accomplished.

As previously stated, IP packet forwarding is enabled at both server/routers. Each server/router is also the designated default gateway for their respective ELAN. This means that all ship workstations must have the ship's server/router IP address entered in the default gateway section of the Microsoft TCP/IP properties dialog box, IP address tab, as displayed in Figure 19.
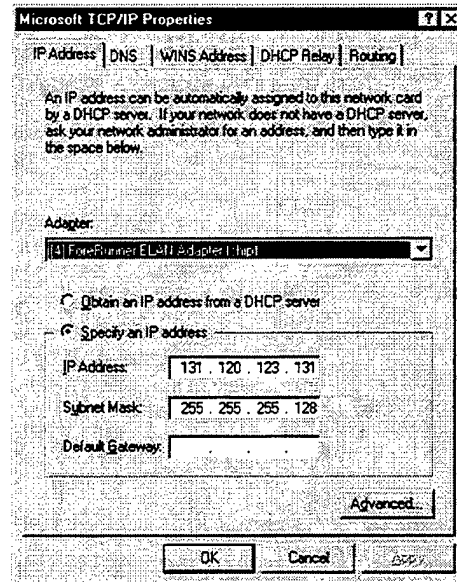
Figure 19. TCP/IP Properties Dialog Box, IP Address Tab, Ship-to-Ship.

Figure 20 illustrates the IP address settings for the ship's server/router properties as a member of the ship's ELAN.
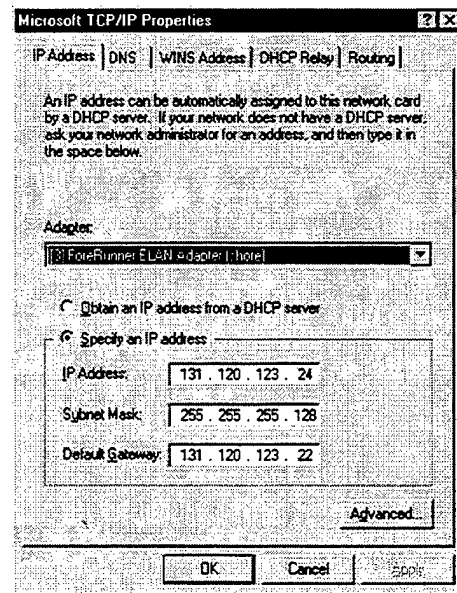
Figure 20. TCP/IP Properties Dialog Box, IP Address Tab, Ship-to-Shore.

In the same way a ship's workstation addresses the ship's server/router, the ship's server/router addresses the shore's server/router. Looking from the shore ELAN to the ship ELAN, the ship's server/router appears to the shore's server/router as just another workstation with an assigned IP address and knows nothing of the network hidden behind

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the ship's server/router. Figure 21 illustrates the establishment of static routes ensuring proper IP traffic flow to and from respective gateways when using RRAS.

Figure 21. Static Routing Dialog Box.

IP addressing does not only apply to Microsoft NT workstations and servers as studied above, but in much the same way the ASX-200 BX was assigned as a LEC, it too can be assigned an IP address. The assigning of IP addresses to the ATM switches enables administrators to telnet into the switch via remote location. This function allows them to remotely load, control and monitor the operation of the ATM switch instead of having to log on locally to the console port of the switch. Once an IP address is assigned, the ASX-200 BX appears to any workstation within the network as another LEC.

Figure 22 is the result of typing the configuration IP> show command within the shore assigned ASX-200 BX. The ship configuration is nearly identical with the exception that el16 is replaced as shown in Table 2. In both instances, the IP forwarding state is set to forwarding. To check the switch IP environment, the command

configuration ip route>sh

is entered and reveals the details shown in Table 3 and Table 4. The G flag in the tables means that it is an indirect route to a gateway [11]. By setting the default destination value to the respective ship or shore gateway, all IP traffic is routed to the appropriate server/router.

```
┌─────────────────────────────────────────────────────────────────────┐
│ ▄▄ Telnet - 131.120.123.20                                  ─ □ ✕    │
│ Connect  Edit  Terminal  Help                                        │
├─────────────────────────────────────────────────────────────────────┤
│                                                                      │
│ Opening a session for "127.0.0.1", please wait...                    │
│                                                                      │
│ Connected to "127.0.0.1" (asx200bx).                                 │
│                                                                      │
│                                                                      │
│ NETLABSW20::> con                                                    │
│                                                                      │
│ NETLABSW20::configuration> ip                                        │
│                                                                      │
│ NETLABSW20::configuration ip> sh                                     │
│                                                                      │
│ interface  state         address         netmask         broadcast          mtu   │
│ lo0        up            127.0.0.1       255.0.0.0        N/A                4096  │
│ ie0        down          131.120.123.160 255.255.255.128  131.120.123.255          │
│ asx0       down                                                      │
│ qaa0       down                                                      │
│ qaa1       down                                                      │
│ qaa2       down                                                      │
│ qaa3       down                                                      │
│ el16       up            131.120.123.20  255.255.255.128  131.120.123.127   1500  │
│                                                                      │
│ IP Forwarding State: forwarding                                      │
│                                                                      │
│ NETLABSW20::configuration ip>                                        │
└─────────────────────────────────────────────────────────────────────┘
```

Figure 22. Shore ASX-200BX Assigned IP Addresses.

Interface	State	Address	Netmask	Broadcast	MTU
el17	up	131.120.123.130	255.255.255.128	131.120.123.255	1500

Table 2. Ship ASX-200BX Assigned IP Addresses.

Destination	Gateway	Metric	Interface	Flags
default	131.120.123.22	1	el16	G
127.0.0.1	127.0.0.1	0	lo0	
131.120.123.0	131.120.123.20	0	el16	

Table 3. Shore ELAN IP Routing Information.

Destination	Gateway	Metric	Interface	Flags
default	131.120.123.131	1	el17	G
127.0.0.1	127.0.0.1	0	lo0	
131.120.123.128	131.120.123.130	0	el17	

Table 4. Ship ELAN IP Routing Information.

This concludes discussion of the network layer. In this chapter, we have discussed the physical layer, data link layer and the network layer. At this point, the simulation model is defined and ready for testing.

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IV. ANALYSIS OF DATA THROUGHPUT OVER AN ATM WAN

In Chapter III, we established a ship-to-shore simulation model, and Figure 11 and Figure 12 illustrated the layout for the single and two (split) ELAN configurations, respectively. Figure 9 focused on an inport situation where a ship ATM ELAN was connected directly to a shore ELAN. A second shore server using a 100 Mbps Fast Ethernet connection was also connected to the shore server. This chapter discusses in detail analysis setup, analysis of inport test results, and analysis of underway test results.

A.   ANALYSIS SETUP

Two software programs were essential in developing the test results. The first program was a generic echo server [12], which was started on the shore server/router. The echo server's purpose was to provide a means of replicating packets sent from a workstation. The second program, Socket Wrencher [13], was configured to transmit and receive TCP packets and determine throughput calculations. Socket Wrencher's configuration dialog box, as displayed in Figure 23, permits the user to input the IP address of the device operating the echo server.
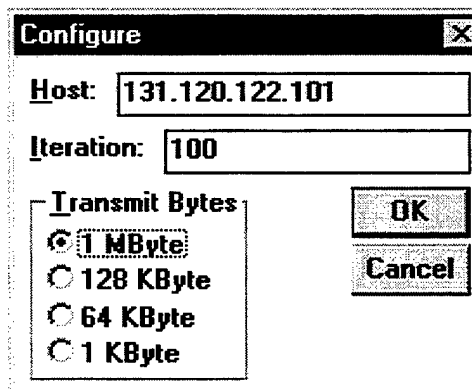
Figure 23. Socket Wrencher Configuration Dialog Box. [13]

All trials conducted used the shore's server/router. When testing the ATM ELANS, the "Host" block was set to IP address 131.120.123.21 whereas testing for the Fast Ethernet connection was directed to IP address 131.120.122.101. Trials with propagation delay greater than 5 ms were run for 20 iterations while all other trials were tested at 100

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iterations. The "Transmit Bytes" block indicated the amount of data (or file size) to send to the echo server in one iteration. Experiments were conducted with transmission sizes of 1 MB, 128 KB, or 64 KB.

The next step in performing a Socket Wrencher test was to select the TCP echo synchronous test icon, which then displayed the dialog box as in Figure 24.
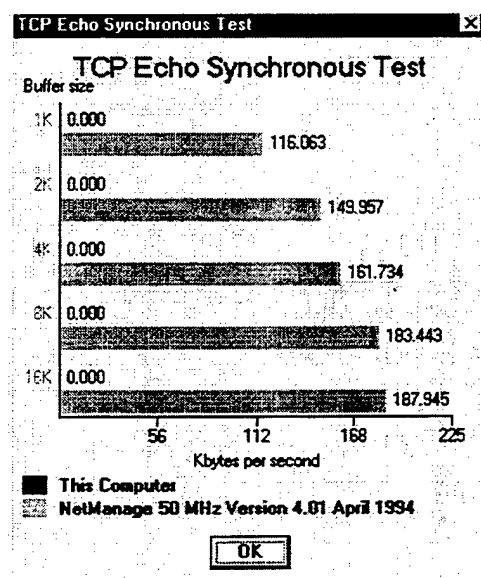
Figure 24. Socket Wrencher TCP Echo Synchronous Test Dialog Box. [13]

Selection of the "OK" button would start the configured trial run. Socket Wrencher is designed to return values for each of the window sizes as displayed in Figure 24. Window size refers to the number of bytes that the receiver is willing to accept. The size of the receive buffer in general is the maximum size of the advertised window for that connection. By default, the window size is limited to a 16-bit field, which limits the window size to 65535 bytes maximum[11]. Window size throughout for this thesis is controlled by the use of the Socket Wrencher program. The Socket Wrencher program is an application, which is capable of changing the socket buffer size to influence performance. Due to problems with the echo service application, the 16-KB window buffer failed to function correctly during testing and was not used. The raw data for all runs is contained in Appendix D. Many trials used the same Socket Wrencher configuration while varying the propagation delay. Consequently, the TCP synchronous test window was closed after each

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trial and the Socket Wrencher program restarted after each run. The purpose for the shutdown and restart cycle was to reset Socket Wrencher after aborting the program when testing went to the 16-KB window buffer size.

Propagation delay throughout all testing was solely controlled by the Adtech SX-14 data channel simulator as illustrated in Figure 11 and Figure 12. The recording of propagation time as discussed throughout this report is one half of the round trip time. All trials used identically set W→ E and E → W propagation delays as detailed in Appendix D. The largest propagation delay tested was set to 250 ms, which is approximately the propagation delay between two earth stations communicating via a geosynchronous satellite.

In summary, throughput calculations displayed on the TCP echo synchronous trial dialog box were calculated in the following manner:

1. The workstations running Socket Wrencher generated and transferred the configured number of bytes.

2. The packets received at the server were sequentially ordered and sent to the echo server application layer program.

3. The echo server regenerated all received packets and echoed them back to the network with the IP address of the originator.

4. The originating workstation, through the use of the Socket Wrencher program, received all packets and determined the throughput for the selected number of iterations based on the elapsed amount of time it took to receive all of the echoed transmitted application layer data.

B.   ANALYSIS OF INPORT SCENARIO

Appendix E contains plots for the three different transmitted file sizes produced using Socket Wrencher with the SX-14 propagation delay set to zero for the inport scenario. A closer analysis of the 1 MB file's throughput yields some interesting results as detailed in Figure 25. Recall that the inport trial was conducted using a single or a split ELAN as well as a 100 Mbps Fast Ethernet connection. Figure 25 illustrates that the throughput of 100 Mbps Fast Ethernet rivals that of a single ELAN operating an OC-3 (155 Mbps) connection. Further analysis of plots in Appendix E indicates that the same is true for the 128 KB and the 64 KB data files as well. The split ELAN in Figure 25 falls short in throughput comparisons against the single ELAN and Fast Ethernet. The best explanation for the

shortcoming of a split ELAN with zero propagation delay is due primarily to the extra processing time required to transfer TCP packets through the ship's server/router.

1MByte data file size (Zero Propagation Delay)
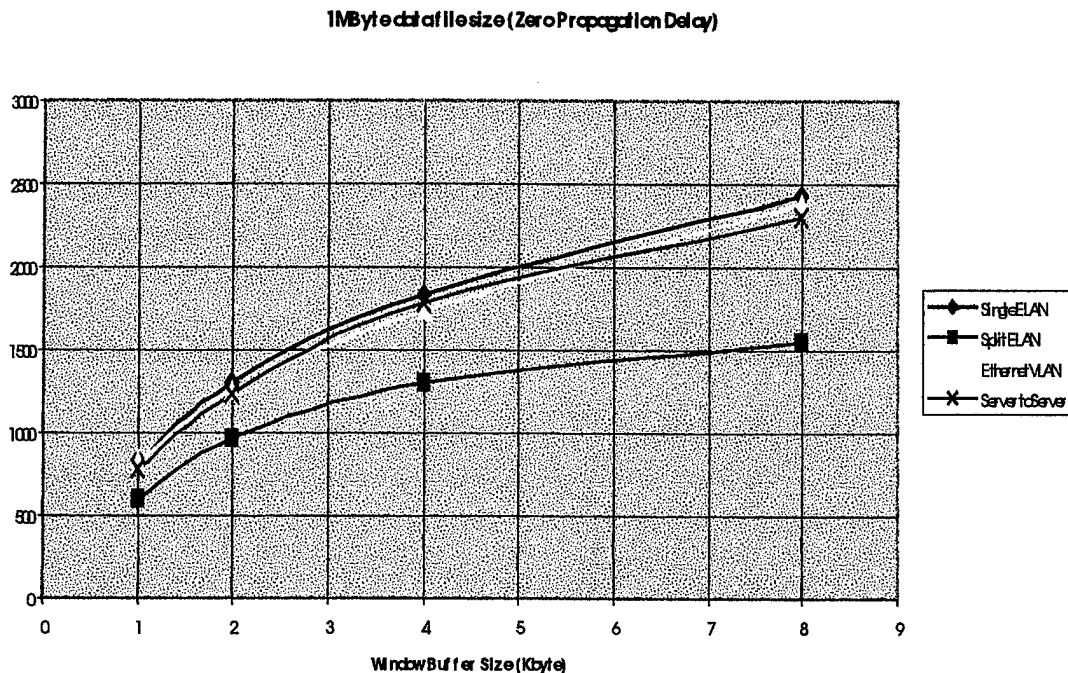
Figure 25. 1MB Data File [Zero Propagation Delay].

Recall from chapter IV section A, throughput tests using Socket Wrencher require that a TCP packet be transmitted, received, and regenerated at the server, and then returned back through the network. In the split ELAN, a single packet must be segmented and reassembled two times within the ship's server/router. This adds processing time, which directly influences throughput as measured by Socket Wrencher.

Proof of this processing delay can be observed in Figure 25 when comparing the single ELAN to the server-server connection. In this trial, Socket Wrencher is run on the ship server/router and connects to the shore server, thus bypassing the routing function. Chapter III states that each of the two server/routers functions using RRAS version 2. RRAS version 2 is a program which provides software routing. Much faster hardware routers are available though not studied in this thesis. A hardware router's throughput capacity could potentially approximate that of the server-server connection. The use of a software router establishes a worst case scenario. Processor speed and available memory also play a role in

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determining the efficiency of software routing. Additionally, the split ELAN workstation traversed two ASX-200 BX switches in reaching the server whereas the single ELAN workstation shared a port on the same switch as the server. Figure 25 also compares the throughput versus window buffer size. It is can be clearly seen that window buffer size is an important element in maximizing throughput during inport scenario.

An analysis of the plots in Appendix E indicates that larger files are better able to take advantage of the larger window buffer size. This analysis may appear to be skewed and misleading; however, on closer examination, smaller file size throughput is more significantly affected by the TCP requirement of "slow start." Slow start is defined as the rate at which new packets should be injected into the network as set by the rate of acknowledgements returned from the receiver end.

Slow start attaches the "congestion window" to the sliding window. The congestion window is initialized to one segment length. This then limits the window size to one segment no matter what the advertised receive window buffer size is initially set to. By default, the sender can transmit up to the minimum of the congestion window and the advertised window. The congestion window provides flow control imposed by the sender while the advertised window provides flow control imposed by the receiver.

The first segment is transmitted, and the sender awaits the acknowledgement from the receiver. Once the transmitter receives the acknowledgement, the window size is incremented to two segments. When each of the two segments are acknowledged at the transmitter, the window is doubled. This process continues until the window buffer size is reached. [11]

Slow start has more of an effect on small file sizes as compared to larger file sizes. The smaller file sizes are nearer to completion on exiting slow start than would be a larger file size, which is allowed to operate at the advertised window size.

One of the principal questions of this thesis is to analyze the benefit of operating either a single, split, or Fast Ethernet network. The inport graphs in Appendix E suggest that the optimum configuration would be to operate all ATM LECs on a single ELAN or Fast Ethernet LAN when transferring "small" files using an 8-KB window buffer; however, an important factor that must be addressed is the amount of overhead data required to

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transmit TCP data over ATM. The small file size used by Socket Wrencher is not indicative of the benefits of using ATM. Much of the reduction in throughput is attributed to call establishment at the TCP and LANE levels. Additional reduction is due to the addition of headers and segmentation and reassembly at the ATM, IP, and TCP layers. Call establishment results are averaged over 100 iterations as the data direct VCC discussed in (see Chapter II) is not dropped until all 100 iterations are complete.

C.   ANALYSIS OF UNDERWAY SCENARIO

The graph of underway results for the 1MB data file is displayed in Figure 26. The rapid transition in throughput in the 0 to 5 ms propagation delay range is clarified in Figure 27. Figure 27 illustrates the convergence of both the single and the split ELAN as well as the 4-KB and 8-KB window buffer size. Once converged at the 5 ms point, all four plots follow the same trend in throughput out to 250 ms of propagation delay as shown in Figure 28.
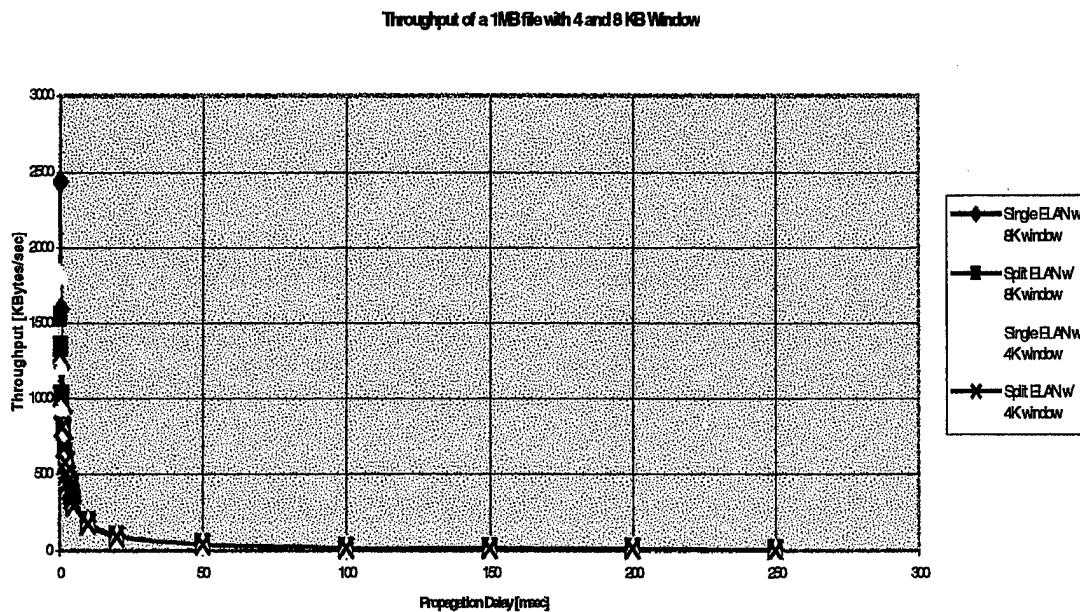
Figure 26. Throughput versus Propagation Delay [0-250 ms] of a 1MB Data File.

Throughput of a 1MB file with 4 and 8 KB Window
(0 - 5 msec Propagation Delay)
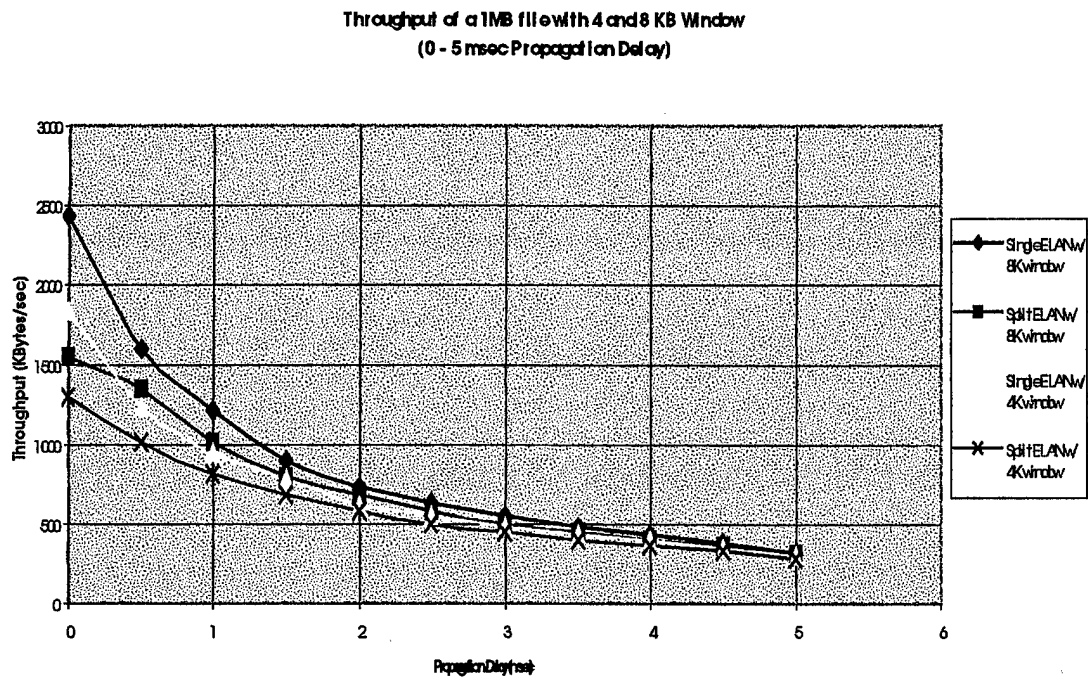
Figure 27. Throughput versus Propagation Delay [0-5 ms] of a 1MB Data File.

Throughput of a 1MB file with 4 and 8 KB Window
(50-250 msec Propagation Delay)
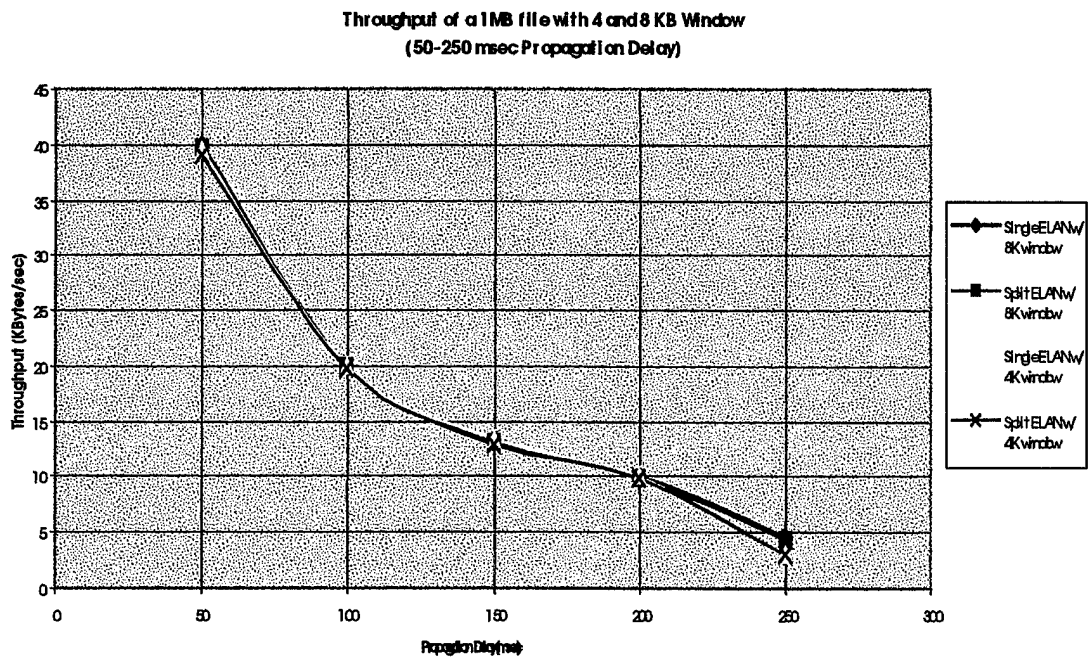
Figure 28. Throughput versus Propagation Delay [50-250 ms] of a 1MB Data File.

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Appendix F contains graphs of all underway trials conducted for all three file sizes within Socket Wrencher. In all cases, the throughput for single and split ELANs converges within 5 ms of propagation delay for each of the data files transferred.

In summary, analysis of the underway trials demonstrates that processing delays become insignificant as propagation delay becomes more dominant. Note that a 5 ms propagation delay equates to 1500 Km or approximately a 900 mile separation between ship and server stations. Therefore, for ships at sea out past the line-of-sight (LoS) communication range, the benefit of a single ELAN over a split ELAN has been overcome by the propagation delay. Consequently, no benefit is gained by placing all LECs within the same ELAN.

V. CONCLUSION

A.   SUMMARY OF WORK

The purpose of this thesis was to design, develop, test and analyze an Emulated LAN (ELAN) system. The objectives of this thesis as detailed in Chapter I were to establish a working ELAN within the NPS Advanced Network Laboratory, to determine the data throughput using various network designs, and to identify an optimal network configuration.

Chapter II laid the foundation for understanding the functionality of LANE. This chapter described the functions of each major component of LANE and how they interoperate. Chapter III presented the implementation of a working ELAN. Chapter IV utilized the various ELAN implementations in Chapter III through the use of an echo server and the Socket Wrencher software to measure throughput values for both "inport" and "underway" scenarios. Results of these measurements are presented in Chapter IV, Appendix E and Appendix F to demonstrate throughput limitations based on propagation delay, process delay, window buffer size, and data file size.

In conclusion, this thesis has provided measured results in terms of throughput for three separate scenarios. As presented in Chapter IV, a network using software routing was the worst-case scenario. Also, if more advanced hardware routing were used, results similar to those observed in the server-to-server plot within Figure 25 could be obtained. The recommendation of this work in regards to connectivity and throughput would be to operate individual units as members of a split ELAN within an ATM network while using hardware internetwork routing. The benefit of utilizing this configuration would be easily realized during the in-chop process as only a single router would require address modifications as compared to an entire network.

B.   FUTURE WORK

The establishment of an operational split ELAN within the NPS Advanced Networking Laboratory has opened the door to several future thesis projects. Some of the possible future studies are listed below:

1. The use of the Socket Wrencher program in calculating throughput was very limiting in the area of file size. Using the underway split ELAN scenario and the lab's EtherPeek network analysis software, a future investigation could determine throughput versus propagation delay of a VTC or streaming video source. The Advanced Networking Laboratory is outfitted with two Logitech QuickCam Pro web cameras to facilitate this study.

2. The available equipment within the Advanced Networking Laboratory provides an excellent setting to study the "man in the middle attack." Through the use of the networking equipment, a miniature Internet could be configured to allow the testing and analysis of this attack.

3. ASX-200BX ATM switches provide an administrator the ability to establish "usage parameter controls." An exploration in configuration and optimization could be implemented in the ship and shore ELANs. Testing conducted throughout this thesis was under optimal conditions. Further study could incorporate the use of the Adtech AX-4000 generator functions to add "bursty traffic" into the scenario and determine the throughput in a "noisy" environment.

4. A computer simulation model of the system described within this thesis can be developed and throughput calculations compared to those in Appendix D.

APPENDIX A. INFORMATION TECHNOLOGY FOR THE TWENTY-FIRST CENTURY (IT-21)

RTTUZYUW RUHPSGG9842 0890945-UUUU--RUWFNAA.
ZNR UUUUU
R 300944Z MAR 97 ZYB PSN 077820Q24
FM CINCPACFLT PEARL HARBOR HI//N00//
TO ALPACFLT
ALLANTFLT
INFO RUENAAA/ASSTSECNAV RDA WASHINGTON DC//C4I//
RUENAAA/CNO WASHINGTON DC//N00/N09/N095/N2/N4/N41/N43/N46/N6/N6B/
   N8/N80/N85/N86/N87/N88//
RUCBCLF/CINCLANTFLT NORFOLK VA//N00/N6//
RUCBACM/CINCUSACOM NORFOLK VA//J00/J6//
RHHMUNA/USCINCPAC HONOLULU HI//J00/J6//
RHDLCNE/CINCUSNAVEUR LONDON UK//00/N6//
RULSSEA/COMNAVSEASYSCOM WASHINGTON DC//N00/N08/PMS335/PMS3
RUENMED/BUMED WASHINGTON DC//N00//
RHRMDAB/RUCJNAV/COMUSNAVCENT//N00/N6//
RUCTPOA/CNET PENSACOLA FL//N00//
RUEACNP/BUPERS WASHINGTON DC//N00//
RUHEHMS/COMMARFORPAC//CG/G6//
RUCKMAA/COMMARFORLANT//CG/G6//
RULSSPA/COMSPAWARSYSCOM WASHINGTON DC//N00/N05/PMW171/PMW176//
RUWFADO/NAVSTKAIRWARCEN FALLON NV//N00//
RULKSDF/COMNAVSECGRU FT GEORGE G MEADE MD//N00//
RULSAMX/COMNAVSUPSYSCOM MECHANICSBURG PA//N00//
RUWFAFK/COMNAVSPECWARCOM CORONADO CA//N00//
RULSADG/NRL WASHINGTON DC//N00//
RULSWCB/COMNAVCOMTELCOM WASHINGTON DC//N00/N3//
RUCOSAO/NAVMASSO CHESAPEAKE VA//N00/N6//
RUWFOAA/NCCOSC RDTE DIV SAN DIEGO CA//N433//
RHHMHAH/CINCPACFLT PEARL HARBOR HI//N00//
BT
UNCLAS //N05230//
ALPACFLT 008/97
MSGID/GENADMIN/CINCPACFLT/008//
SUBJ/INFORMATION TECHNOLOGY FOR THE 21ST CENTURY//
POC/M.R. SCOTT/CDR N6/CINCPACFLT/-/TEL: 808 471-8637//
POC/D.A. STRAUB/CDR N6/CINCLANTFLT/-/TEL: 757 322-5863//
RMKS/1. THIS IS THE FIRST IN A SERIES OF JOINT CINCPACFLT AND CINCLANTFLT MESSAGES CONCERNING THE DEVELOPMENT AND IMPLEMENTATION OF IT-21. THIS MESSAGE PROVIDES IT-21 HARDWARE/SOFTWARE IMPLEMENTATION STANDARDS FOR PROGRAMS INSTALLING INFORMATION SYSTEMS ON FLEET UNITS/BASES AND PROVIDES THE FLEET WITH GUIDANCE ON MAINTAINING EXISTING INFORMATION SYSTEMS UNTIL INSTALLATION OF IT-21 PRODUCTS. THE IT-21 IMPLEMENTATION STANDARDS OUTLINED BELOW ARE PROMULGATED IN ADVANCE OF DON-WIDE GUIDANCE FROM THE DON CHIEF INFORMATION OFFICER (CIO). THE DON CIO WILL PROMULGATE DON-WIDE STANDARDS FOLLOWING NEGOTIATION OF ENTERPRISE-WIDE NETWORK OPERATING SYSTEMS AND APPLICATIONS.

2. BACKGROUND: INFORMATION SUPERIORITY IS THE FOUNDATION OF JOINT VISION 2010 BATTLEFIELD DOMINANCE, AS WELL AS THE WARFIGHTING VISION FOR EACH SERVICE. NETWORK WARFARE, ROBUST INFRASTRUCTURE AND INFORMATION DISSEMINATION TO DISPERSED FORCES ARE KEY ELEMENTS IN ACHIEVING INFORMATION SUPERIORITY. IT-21 IS A FLEET DRIVEN REPRIORITIZATION OF C4I PROGRAMS OF RECORD TO ACCELERATE THE TRANSITION TO A PC BASED TACTICAL/TACTICAL SUPPORT WARFIGHTING NETWORK. THE INACTIVATION OF THE CURRENT DOD MESSAGING SYSTEM (AUTODIN) BY DEC 99, WITH NO PLANNED NAVY INFRASTRUCTURE REPLACEMENT, MANDATES THE RAPID IMPLEMENTATION OF THIS WARFIGHTING NETWORK.

3. COMMERCIAL NETWORK OPERATING SYSTEMS (NOS) AND E-MAIL PRODUCTS HAVE ACHIEVED FUNCTIONAL PARITY. THE FLEETS CANNOT CONTINUE TO SUPPORT A MULTITUDE OF DIVERSE OPERATING SYSTEMS AND E-MAIL PRODUCTS WITH THEIR OWN TRAINING, OPERATIONAL PROCEDURES AND TROUBLESHOOTING REQUIREMENTS. THE DOD JOINT TECHNICAL ARCHITECTURE (JTA) AND DEFENSE INFORMATION INFRASTRUCTURE COMMON OPERATING ENVIRONMENT (DII COE) PROVIDE DOD WITH THE AIS SYSTEM GUIDANCE REQUIRED TO TAKE THE NAVY INTO THE 21ST CENTURY. THIS CONVERGENCE OF SOLUTIONS, PROBLEMS AND GUIDANCE PROVIDES THE IMPETUS TO ESTABLISH MINIMUM NAVY AIS STANDARDS AT THIS TIME. IMPLEMENTATION OF THIS POLICY REQUIRES ALL NON-STANDARD NOS AND E-MAIL PRODUCTS BE REPLACED NLT DEC 99.

A. WINDOWS NT SERVER 4.0 IS THE STANDARD FLEET NOS. IT WILL SOON BE FOLLOWED BY WINDOWS NT 5.0. WINDOWS NT SERVER 4.0 IS DII COE COMPLIANT.

B. MS EXCHANGE IS DESIGNATED AS THE STANDARD E-MAIL SOLUTION FOR BOTH FLEETS TO ENSURE AN INTEROPERABLE SECURE MESSAGING SYSTEM IS OPERATIONAL PRIOR TO AUTODIN INACTIVATION NLT DEC 99.

C. MS OFFICE 97 IS DESIGNATED AS THE STANDARD FLEET OFFICE SOFTWARE.

D. EXPENDITURE OF OPERATING FUNDS TO MAINTAIN EXISTING IT-21 NONCOMPLIANT NOS AND APPLICATIONS SHALL BE THE ABSOLUTE MINIMUM NECESSARY TO MEET OPERATING REQUIREMENTS UNTIL IT-21 NOS/SOFTWARE IS INSTALLED EVEN IF TEMPORARY LN DEGRADATION OCCURS. SOFTWARE REQUIREMENTS DRIVE HARDWARE STANDARDS. HARDWARE AND SOFTWARE PURCHASED TODAY MUST BE CAPABLE OF MEETING MISSION REQUIREMENTS THROUGH THE YEAR 2000.

4. CINCPACFLT AND CINCLANTFLT ARE ACTIVELY WORKING WITH OPNAV ON IT-21 FUNDING AND IMPLEMENTATION PLANS. IN GENERAL, AFLOAT IT-21 IMPLEMENTATION WILL BE LINKED TO DEPLOYING BATTLEGROUPS AND ASHORE IT-21 WILL BE IMPLEMENTED IN A PHASED APPROACH. SPECIFIC IMPLEMENTATION SCHEDULES WILL BE PROMULGATED AT A LATER DATE. CINCPACFLT AND CINCLANTFLT ARE TRANSITIONING TO WINDOWS NT 4.0, MS EXCHANGE AND MICROSOFT OFFICE 97. THIS ENVIRONMENT CANNOT BE OPTIMIZED WITHOUT 32 BIT OPERATING SYSTEMS, HIGH RESOLUTION DISPLAYS AND MASS STORAGE. ATM BACKBONE LANS WITH AT LEAST 100 MBS (TCP/IP)TO THE DESKTOP PC WILL BE INSTALLED ON ALL SHIPBOARD LANS, FLEET HEADQUARTERS (CPF, CLF, TYCOMS, GROUP AND SQUADRON COMMANDS) AND SHOULD BE INSTALLED IN THOSE SHORE ACTIVITIES THAT SUPPORT TACTICAL OPERATIONS. THIS WILL THEN ALLOW TRANSITION TO ATM-TO- THE-DESKTOP PC WHEN THE ATM TECHNOLOGY MATURES.

5. SYSTEM COMMANDS AND PROGRAM MANAGERS:

A.   NTCSS WILL BECOME THE IT-21 PROGRAM OF RECORD FOR INSTALLATION OF BOTH SECRET AND UNCLASSIFIED LANS ONBOARD COMMISSIONED SHIPS. NTCSS (ATIS/SNAP III) LANS INSTALLED FROM THIS POINT ON WILL HAVE AN ATM BACKBONE, 100 MBS (FAST ETHERNET) TO THE DESKTOP PC AND THE HARDWARE/SOFTWARE OUTLINED AT THE END OF THIS MESSAGE. THE MIGRATION OF NTCSS LANS TO HIGHER CAPACITY LANS WILL REDUCE THE NUMBER OF PC'S DELIVERED DURING INITIAL INSTALLATION. THE TRADE-OFF OF QUANTITY FOR FRONT END PC'S IS REQUIRED TO SUPPORT JV-2010 AND AUTODIN INACTIVATION.

B. SPAWAR IS WORKING WITH NAVSEA TO ENSURE THAT LANS INSTALLED DURING NEW CONSTRUCTION MEET THE IT-21 REQUIREMENTS.

C. APPLICATION PROGRAM MANAGERS SUCH AS JMCIS, NSIPS, TAMPS, AND GCSS SHOULD MIGRATE CURRENT APPLICATIONS TO THE DII COE WITH AN IMMEDIATE OBJECTIVE OF OBTAINING PC WORKSTATION ACCESS TO ALL APPLICATION DATA ON AN ENTERPRISE LAN.

D. PROGRAMS INSTALLING INFORMATION SYSTEMS (NEWNET, SMARTLINK, SMARTBASE, TELEMEDICINE, ETC.) MUST INSTALL COMPONENTS IN FLEET ACTIVITIES THAT MEET IT-21 STANDARDS AND PROVIDE INTEROPERABILITY THROUGHOUT THE WARFIGHTING NETWORK.

6. TYCOMS AND THIRD ECHELON COMMANDS SHALL ENSURE THAT:

A.   SHIPS AND ACTIVITIES INSTALLING NEW LANS, UNDERGOING SIGNIFICANT LAN UPGRADES OR THOSE ACTIVITIES WITH STAND ALONE PC'S SHALL INSTALL IT-21 HARDWARE AND SOFTWARE. NEW OR REPLACEMENT SHIPBOARD AND SHORE BASED TACTICAL LANS SHOULD HAVE AN ATM BACKBONE WITH AT LEAST 100 MBS (FAST ETHERNET) TO THE PC.

B.   SHIPS AND ACTIVITIES WITH EXISTING LANS, WHICH REQUIRE REPLACEMENT OF UNSERVICEABLE HARDWARE, SHORT OF A FULL NETWORK UPGRADE, SHALL INSTALL HARDWARE WHICH MEETS IT-21 STANDARDS. THE NEW EQUIPMENT MAY NOT BE COMPATIBLE WITH THE EXISTING LAN HARDWARE. CINCPACFLT AND CINCLANTFLT BELIEVE THAT ALL AUTOMATED INFORMATION SYSTEMS (AIS) PROCURED MUST BE COMPATIBLE WITH THE IT-21 LAN STANDARDS EVEN IF TEMPORARY LAN DEGRADATION OCCURS. THERE IS ONLY SUFFICIENT FUNDING TO DO IT RIGHT THE FIRST TIME.

7. THE IT-21 STANDARDS BELOW REPRESENT FRONT END MARKET TECHNOLOGY, ARE DYNAMIC IN NATURE, AND WILL CONTINUE TO BE CLOSELY LINKED TO COMMERCIAL TRENDS. THE STANDARDS LISTED BELOW ARE INTENDED TO BE MINIMUM STANDARDS AND WILL BE UPDATED PERIODICALLY.

A. IT-21 LAN:

(1) AFLOAT LAN STANDARDS - ATM FIBER BACKBONE, 100 MBPS (FAST ETHERNET) TO THE PC.

(2) ASHORE TACTICAL AND HEADQUARTERS COMMAND CENTER STANDARD (CPF, CLF, TYCOMS, GROUP AND SQUADRON COMMANDS) – ATM BACKBONE, 100 MBPS (FAST ETHERNET) TO THE PC.

(3) ASHORE TACTICAL SUPPORT COMMAND STANDARDS (BASES) – ATM BACKBONE, 100 MBPS (FAST ETHERNET) TO THE PC.

(4) METROPOLITAN AREA NETWORKS (MAN) SHOULD BE CAPABLE OF SUPPORTING AT LEAST OC-3 (155MBS).

B. IT-21 SOFTWARE:

- WINDOWS NT 4.0/5.0 WORKSTATION
- MS OFFICE 97 PROFESSIONAL (WORD 97, POWERPOINT 97, EXCEL 97, S
ACCESS 97)
- IBM ANTI VIRUS (NAVY LICENSE, AVAIL FROM NAVCIRT)
- MS BACK OFFICE CLIENT
- MS OUTLOOK 97
- MS EXCHANGE 5.0
- MS IMAGE COMPOSER

C. IT-21 DATABASES. RELATIONAL DATABASES THAT CAN SUPPORT WEB TECHNOLOGY IAW THE COE (ORACLE, SYBASE, SQL SERVER, ACCESS, ETC.) WILL BE USED TO SUPPORT DATA REQUIREMENTS AND APPLICATION DEVELOPMENT. ALL PROCESS ENGINEERING INITIATIVES THAT RESULT IN DESIGN/REDESIGN OF A DATA COLLECTION/CAPTURE SYSTEM MUST USE COE COMPLIANT RELATIONAL DATABASE MANAGEMENT SYSTEMS (RDBMS) SOFTWARE. THIS REQUIREMENT IS PROVIDED TO ENSURE RDBMS INITIATIVES USE COTS APPLICATION SOFTWARE. FOR ADDITIONAL INFORMATION ON RELATIONAL DATABASES CONTACT CDR SANDY BUCKLES, CPF N67, COMM/DSN (808) 474-6384, NIPRNET mailto:U67@CPF-EMH.CPF.NAVY.MIL.

D. MINIMUM IT-21 PC CAPABILITIES: CPF CAN CURRENTLY PURCHASE THE IT-21 STANDARD PC WITH SOFTWARE FOR $3250.00 - $3579.00 – SEE PARA 7(H) AND 7(I).
- 200 MHZ PENTIUM PRO CPU
- 64 MB EDO RAM
- 3.0 GB HARD DRIVE
- 3.5 INCH FLOPPY DISK DRIVE
- 8X IDE CD-ROM
- DUAL PCMCIA/PC CARD READER
- PCI VIDEO W/2MB RAM
- 17 INCH MONITOR (1280 X 1024)
- POINTING DEVICE (TRACKBALL OR MOUSE)
- SOUNDBLASTER (COMPATIBLE) AUDIO CARD WITH SPEAKERS KEYBOARD
- CPU COMPATIBLE 100 MBPS FAST ETHERNET NIC

E. STANDARD IT-21 LAPTOP WORKSTATION: APPROXIMATELY $5300 –
SEE PARA 7(H).
- 150 MHZ PENTIUM
- 32 MB EDO RAM
- 12.1 IN SVGA ACTIVE MATRIX COLOR DISPLAY
- 2.1 GB EIDE HDD
- 6X INTERNAL CD-ROM
- MODEM, PCMCIA SLOTS, NIC CARD
- SMART LITHIUM BATTERY

F. IT-21 NT FILE SERVER FOR DIRECTORY NETWORK SERVICE: APPROXIMATELY $26K – SEE PARA 7(H). THESE ARE MINIMUM SPECIFICATIONS. NEEDS OF THE SPECIFIC NETWORK WILL DICTATE REQUIREMENTS.
- DUAL 166 MHZ PENTIUM CPU
- 512K SECONDARY CACHE MEMORY- 256 MB RAM
- TWO 4 GB SCSI HDD
- ONE 6 GB DAT DRIVE
- ONE 3.5 INCH FLOPPY DISK DRIVE
- 6X SCSI CD-ROM
- DUAL PCMCIA/PC CARD READER
- 2 DPT SCSI III CACHING CONTROLLERS (SMARTCACHE 4)
- PCI VIDEO W/2MB RAM
- 17 INCH MONITOR (1280 X 1024)
- POINTING DEVICE (TRACKBALL OR MOUSE)
- KEYBOARD
- TWO CABLETRON CPU COMPATIBLE ATM NIC CARDS
-    ANTEC DUAL POWER SUPPLY CASE (HOT SWAPPABLE)

G. IT-21 FILE SERVER/APPLICATION SERVER: APPROXIMATELY $26K – SEE PARA 7(H). SAME AS IT-21 NT FILE SERVER FOR DIRECTORY NETWORK SERVICE WITH THE FOLLOWING CHANGES:
- CHANGE HDD RQRMT TO FIVE 4 GB DRIVES
- CHANGE DAT TO 18 GB.
H. PRICES FOR PC TECHNOLOGY ARE CONSTANTLY CHANGING AND CAN VARY GREATLY DEPENDING ON METHOD OF PROCUREMENT. FOR EXAMPLE, ON 28 MAR 97 AN IT-21 PC PURCHASED DIRECTLY FROM A VENDOR COSTS $3643. GOVERNMENT RATE FOR SMALL PURCHASES (LESS THAN TEN) IS $3579. A BULK PROCUREMENT (MORE THAN SEVENTY-FIVE) COSTS $3250. THE ABOVE PRICES INCLUDE SHIPPING. BULK PROCUREMENTS SHOULD BE MADE THROUGH THE TYPE COMMANDERS WHEN APPROPRIATE. MR. RICK KOOKER, CPF N65, COMM/DSN☻808) 474-5882, NIPRNET: U65@CPF-EMH.CPF.NAVY.MIL IS AVAILABLE TO ASSIST TYCOMS WITH AIS PROCUREMENT ISSUES.
I. AS NETWORK COMPUTER TECHNOLOGY EVOLVES SOME COMMANDS MAY BE ABLE TO TRANSITION TO NETWORK COMPUTERS. WHEN CONSIDERING INSTALLATION OF NETWORK COMPUTERS, TOTAL NETWORK COST MUST BE EVALUATED. NETWORK COMPUTERS HAVE NOT MATURED SUFFICIENTLY TO IMPLEMENT THEM IN FLEET PLATFORMS AT THIS TIME.

8. WAIVER REQUESTS FROM THE ABOVE STANDARDS SHOULD BE SUBMITTED DIRECTLY TO THE RESPECTIVE CPF/CLF N6. POINTS OF CONTACT ARE AS FOLLOWS:
A. CINCLANTFLT: CDR DEBRA STRAUB AT COMM (757) 322-5863, NIPRNET: mailto:U6@CLF.NAVY.MIL
B. CINCPACFLT: CDR MIKE SCOTT AT COMM (808) 474-7860, NIPRNET:U6@CPF-EMH.CPF.NAVY.MIL//
BT
#9842
NNNN

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APPENDIX B. LECS CONFIGURATION FILE, LECS.CFG

```
#
# The search ordering of ELAN names
#
Match.Ordering:        shore, ship
#
.Maximum_Frame_Size:    1516
#
shore.Accept:          xx.xxxx.xx.xxxxxx.xxxx.xxxx.xxxx.xxxxxxxxxxxx.xx
shore.Address:         47.0005.80.FFE100.0000.F21A.44A2.0020481A44A2.01
shore.BUS_Address:     47.0005.80.FFE100.0000.F21A.44A2.0020481A44A2.01
shore.LAN_Name:        shore
#
ship.Accept:           xx.xxxx.xx.xxxxxx.xxxx.xxxx.xxxx.xxxxxxxxxxxx.xx
ship.Address:          47.0005.80.FFE100.0000.F21A.3E9A.0020181A3E9A.02
ship.BUS_Address:      47.0005.80.FFE100.0000.F21A.3E9A.0020181A3E9A.02
ship.LAN_Name:         ship
```

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APPENDIX C. ASX-200BX COMMAND LINE: CONFIGURATION LANE
LES>SHOW ADVANCED

NETLABSW20::configuration lane les> sh advanced

ELAN Name: "**shore**"

LES: 47.0005.80.FFE100.0000.F21A.44A2.0020481A44A2.01

BUS: 47.0005.80.FFE100.0000.F21A.44A2.0020481A44A2.01

LAN Type: Ethernet/IEEE 802.3 Maximum Data Frame Size: 1516

Non-proxy Control Distribute VCC: 0.74

   Proxy Control Distribute VCC: -.-

     Multicast Forward VCC: 0.76

Number of local clients: 4

LEC #1 at 47.0005.80.FFE100.0000.F21A.44A2.00204804EC43.00 (v1,non-proxy)

  00-20-48-04-EC-43 -> 47.0005.80.FFE100.0000.F21A.44A2.00204804EC43.00

  Control Direct VCC: 0.73

LEC #2 at 47.0005.80.FFE100.0000.F21A.44A2.00204804ED54.01 (v1,non-proxy)

  00-20-48-04-ED-54 -> 47.0005.80.FFE100.0000.F21A.44A2.00204804ED54.01

  Control Direct VCC: 0.78

LEC #3 at 47.0005.80.FFE100.0000.F21A.3E9A.00204804EA93.02 (v1,non-proxy)

  00-20-48-04-EA-93 -> 47.0005.80.FFE100.0000.F21A.3E9A.00204804EA93.02

  Control Direct VCC: 0.80

LEC #4 at 47.0005.80.FFE100.0000.F21A.44A2.0020481A44A2.10 (v1,non-proxy)

  00-20-48-1A-44-A2 -> 47.0005.80.FFE100.0000.F21A.44A2.0020481A44A2.10

  Name: SHORE

  Control Direct VCC: 0.85

ELAN Name: "**ship**"

  LES: 47.0005.80.FFE100.0000.F21A.3E9A.0020481A3E9A.02

  BUS: 47.0005.80.FFE100.0000.F21A.3E9A.0020481A3E9A.02

LAN Type: Ethernet/IEEE 802.3 Maximum Data Frame Size: 1516

  Non-proxy Control Distribute VCC: 0.90

    Proxy Control Distribute VCC: -.-

      Multicast Forward VCC: 0.92

Number of local clients: 3

LEC #1 at 47.0005.80.FFE100.0000.F21A.3E9A.00204804ED46.00 (v1,non-proxy)

  00-20-48-04-ED-46 -> 47.0005.80.FFE100.0000.F21A.3E9A.00204804ED46.00

  Control Direct VCC: 0.89

LEC #2 at 47.0005.80.FFE100.0000.F21A.3E9A.00204804EA93.00 (v1,non-proxy)

  02-20-48-04-EA-93 -> 47.0005.80.FFE100.0000.F21A.3E9A.00204804EA93.00

  Control Direct VCC: 0.94

LEC #3 AT 47.0005.80.FFE100.0000.F21A.3E9A.0020481A3E9A.11 (v1,non-proxy)

  00-20-48-1A-3E-9A -> 47.0005.80.FFE100.0000.F21A.3E9A.0020481A3E9A.11

  Name: SHIP

  Control Direct VCC: 0.99

APPENDIX D. RAW DATA FROM SOCKET WRENCHER TRIALS.

Zero Propagation Delay

1M				
Window	Single	Split	Ethernet	ShipServ
1	841.59	603.27	827.062	791.203
2	1293.33	960.561	1250.402	1230.509
4	1828.89	1298.65	1729.779	1779.113
8	2438.097	1545.753	2388.573	2293.334
128K				
Window	Single	Split	Ethernet	ShipServ
1	853.333	640.00	826.027	788.48
2	1351.68	648.907	1331.2	1280
4	1904.64	1464.32	1781.76	1761.28
8	2054.702	1751.04	2074.81	2050.979
64K				
Window	Single	Split	Ethernet	ShipServ
1	866.16	686.96	849.92	814.08
2	1042.432	936.96	1040.756	1035.729
4	1077.62	1099.188	1082.647	1080.971
8	1101.079	1072.593	1104.43	1099.403

5msec Propagation Delay

1M		
Window	Single	Split
1	86.732	87.72
2	160.421	165.39
4	300.167	311.312
8	332.683	337.234
128K		
Window	Single	Split
1	84.48	87.374
2	164.103	164.759
4	292.571	290.743
8	319.391	314.514
64K		
Window	Single	Split
1	88.99	87.721
2	172.373	162.133
4	294.4	273.067
8	307.2	294.4

10msec Propagation Delay

1M		
Window	Single	Split
1	48.178	47.163
2	93.388	91.982
4	181.614	175.826
8	189.692	184.336
128K		
Window	Single	Split
1	47.741	46.816
2	92.889	90.865
4	169.354	163.446
8	174.545	170.667
64K		
Window	Single	Split
1	47.543	46.343
2	91.927	88.436
4	156.038	152.381
8	162.133	158.476

20msec Propagation Delay

1M		
Window	Single	Split
1	24.795	24.53
2	49.118	48.39
4	95.504	94.008
8	97.86	96.112
128K		
Window	Single	Split
1	22.311	24.381
2	48.422	47.176
4	88.858	87.559
8	90.46	89.246
64K		
Window	Single	Split
1	24.381	24.154
2	47.543	47.1
4	82.38	81.067
8	84.021	82.051

50msec Propagation Delay

1M		
Window	Single	Split
1	10.094	10.056
2	20.094	19.983
4	39.502	39.133
8	39.896	39.606
128K		
Window	Single	Split
1	10.025	9.985
2	19.771	19.648
4	36.704	36.411
8	36.904	36.704
64K		
Window	Single	Split
1	9.942	9.904
2	19.907	19.414
4	33.748	33.528
8	34.023	33.968

100msec Propagation Delay

1M		
Window	Single	Split
1	5.078	5.068
2	10.122	10.092
4	19.959	19.844
8	19.997	19.988
128K		
Window	Single	Split
1	5.039	5.031
2	9.99	9.968
4	18.509	18.202
8	18.468	18.534
64K		
Window	Single	Split
1	5.002	5.001
2	9.832	9.686
4	16.817	16.861
8	17.125	17.097

150msec Propagation Delay

1M		
Window	Single	Split
1	3.392	3.388
2	6.769	6.754
4	13.308	12.948
8	13.365	13.132
128K		
Window	Single	Split
1	3.368	3.364
2	6.682	6.637
4	12.269	12.31
8	12.365	12.303
64K		
Window	Single	Split
1	3.341	3.337
2	6.577	6.566
4	11.353	11.116
8	11.297	11.423

200msec Propagation Delay

1M		
Window	Single	Split
1	2.546	2.544
2	5.083	5.072
4	10.021	9.798
8	10.061	9.962
128K		
Window	Single	Split
1	2.529	2.527
2	5.012	4.983
4	9.301	9.12
8	9.271	9.276
64K		
Window	Single	Captain
1	2.529	2.507
2	5.012	4.935
4	9.301	8.537
8	9.271	8.517

250msec Propagation Delay

1M Window	Single	Split
1	2.038	2.036
2	4.066	4.062
4	2.892	2.887
8	4.701	4.264

128K Window	Single	Split
1	1.949	2.023
2	3.868	4.005
4	4.934	4.756
8	5.97	6.053

64K Window	Single	Split
1	1.936	1.973
2	3.79	3.861
4	6.68	6.818
8	6.889	6.889

1MByte File 8KByte Buffer

Delay [msec]	Single	Split
0	2438.097	1545.753
0.5	1599.192	1348.253
1	1210.548	1021.411
1.5	908.041	807.375
2	734.73	677.681
2.5	637.292	581.588
3	547.293	507.066
3.5	484.001	450.032
4	426.944	404.439
4.5	390.248	368.626
5	319.391	314.514
10	189.692	184.336
20	97.86	96.112
50	39.896	39.606
100	19.997	19.988
150	13.365	13.132
200	10.061	9.962
250	4.701	4.264

1MByte File

Delay [msec]	4KByte Buffer Single	Split	2KByte Buffer Single	Split	1KByte Buffer Single	Split
0	1828.89	1298.65	1293.33	960.561	841.59	603.27
0.5	1227.288	1016.667	780.953	649.067	456.65	390.662
1	953.138	808.885	562.758	493.384	313.172	281.865
1.5	779.429	676.812	437.33	396.259	234.444	220.762
2	610.448	578.505	359.45	331.556	195.057	181.597
2.5	556.059	507.258	297.401	285.237	161.388	153.381
3	488.263	450.413	266.036	249.835	141.521	133.871
3.5	439.277	404.401	236.184	222.974	123.104	118.388
4	393.49	368.359	211.688	200.893	110.836	106.187
4.5	357.4	336.62	191.647	182.506	99.509	96.064
5	292.571	290.743	164.103	164.759	84.48	87.374
10	181.614	175.826	93.388	91.982	48.178	47.163
20	95.504	94.008	49.118	48.39	24.795	24.53
50	39.502	39.133	20.094	19.983	10.094	10.056
100	19.959	19.844	10.122	10.092	5.078	5.068
150	13.308	12.948	6.769	6.754	3.392	3.388
200	10.021	9.798	5.083	5.072	2.546	2.544
250	2.892	2.887	4.066	4.062	2.038	2.036

128KByte File 8KByte Buffer

Delay [msec]	Single	Split
0	2054.702	1751.04
5	319.391	314.514
10	189.692	170.667
20	97.86	89.246
50	36.904	36.704
100	18.468	18.534
150	12.365	12.303
200	9.271	9.276
250	5.97	6.053

64KByte File 8KByte Buffer

Delay [msec]	Single	Split
0	1101.079	1072.593
5	307.2	294.4
10	162.133	158.476
20	84.021	82.051
50	34.023	33.968
100	17.125	17.097
150	11.297	11.423
200	9.271	8.517
250	6.889	6.889

128 KByte File 4KByte Buffer

Delay [msec]	Single	Captain
0	1904.64	1464.32
5	292.571	290.743
10	181.614	163.446
20	95.504	87.559
50	36.704	36.411
100	18.509	18.202
150	12.269	12.31
200	9.301	9.12
250	4.934	4.756

64 KByte File 4KByte Buffer

Delay [msec]	Single	Split
0	1077.62	1099.188
5	294.4	273.067
10	156.038	152.381
20	82.38	81.067
50	33.748	33.528
100	16.817	16.861
150	11.353	11.116
200	9.301	8.537
250	6.68	6.818

128 KByte File 2KByte Buffer

Delay [msec]	Single	Split
0	1351.68	648.907
5	164.103	164.759
10	93.388	90.865
20	49.118	47.176
50	19.771	19.648
100	9.99	9.968
150	6.682	6.637
200	5.012	4.983
250	3.868	4.005

64 KByte File 2KByte Buffer

Delay [msec]	Single	Split
0	1042.432	936.96
5	172.373	162.133
10	91.927	88.436
20	47.543	47.1
50	19.907	19.414
100	9.832	9.686
150	6.577	6.566
200	5.012	4.935
250	3.79	3.861

128 KByte File 1KByte Buffer

Delay [msec]	Single	Split
0	853.333	640.00
5	84.48	87.374
10	48.178	46.816
20	24.795	24.381
50	10.025	9.985
100	5.039	5.031
150	3.368	3.364
200	2.529	2.527
250	1.949	2.023

64 KByte File 1KByte Buffer

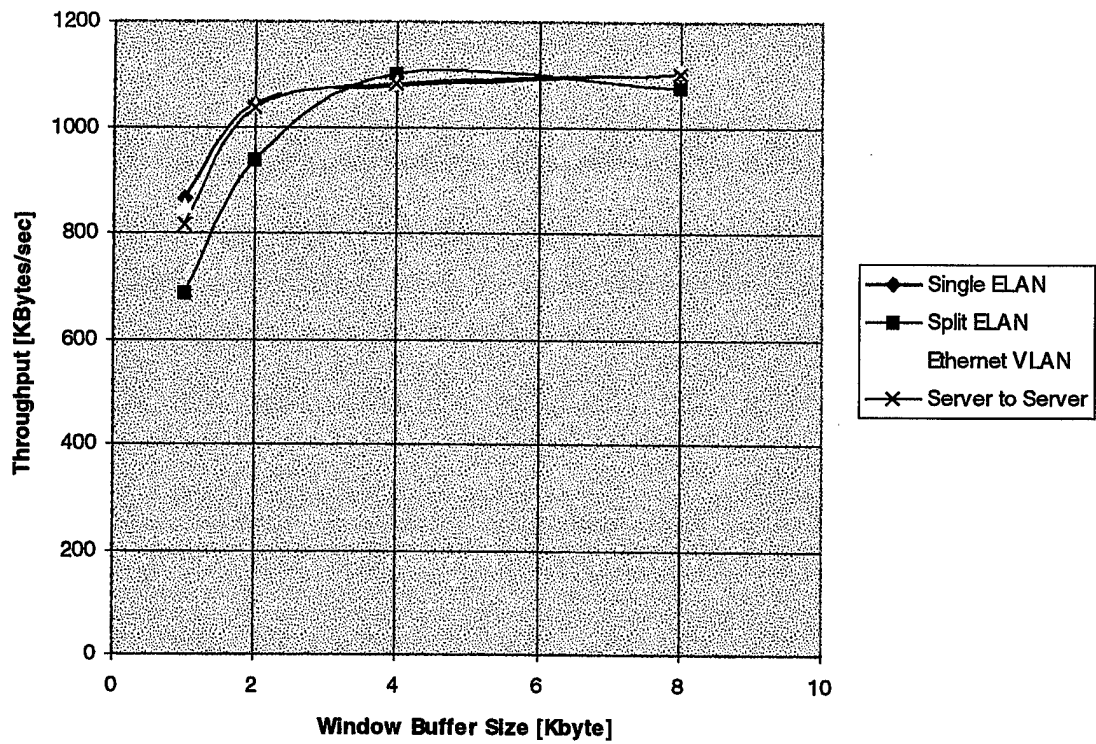| Delay [msec]	Single	Split
0	866.16	686.96
5	88.99	87.721
10	47.543	46.343
20	24.381	24.154
50	9.942	9.904
100	5.002	5.001
150	3.341	3.337
200	2.529	2.507
250	1.936	1.973

APPENDIX E. PLOTS FOR INPORT SCENARIO.

1MByte data file size [Zero Propagation Delay]
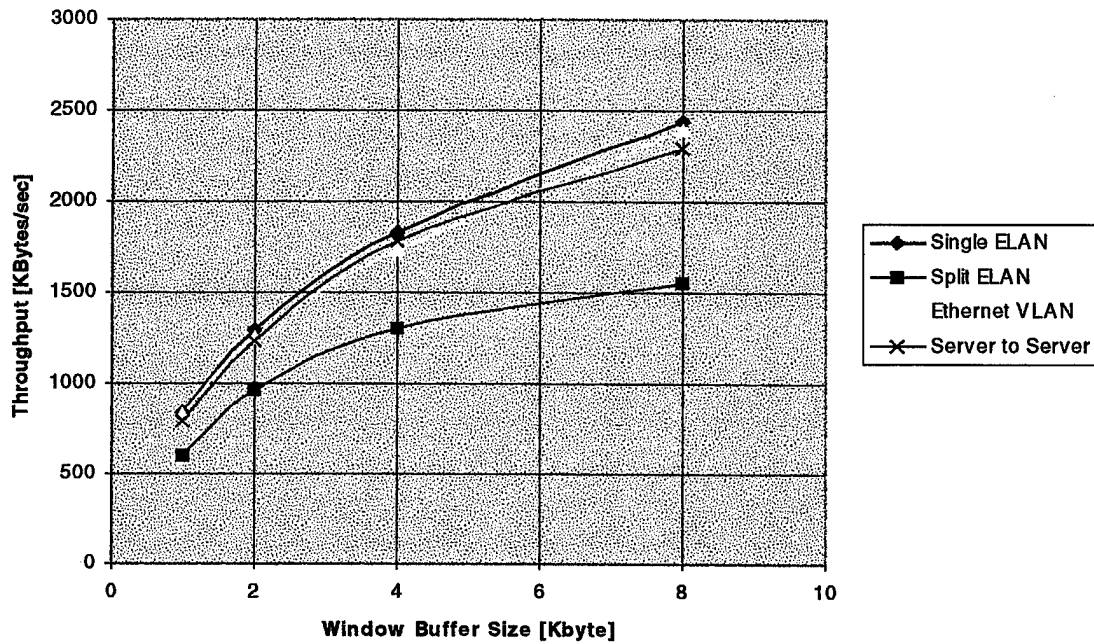
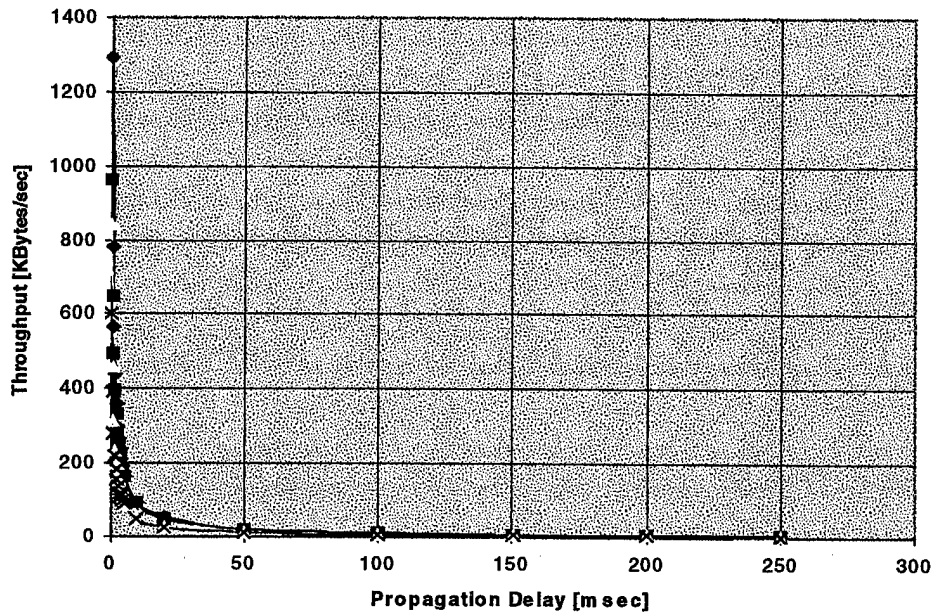**128KB data file size [Zero Propagation Delay]**
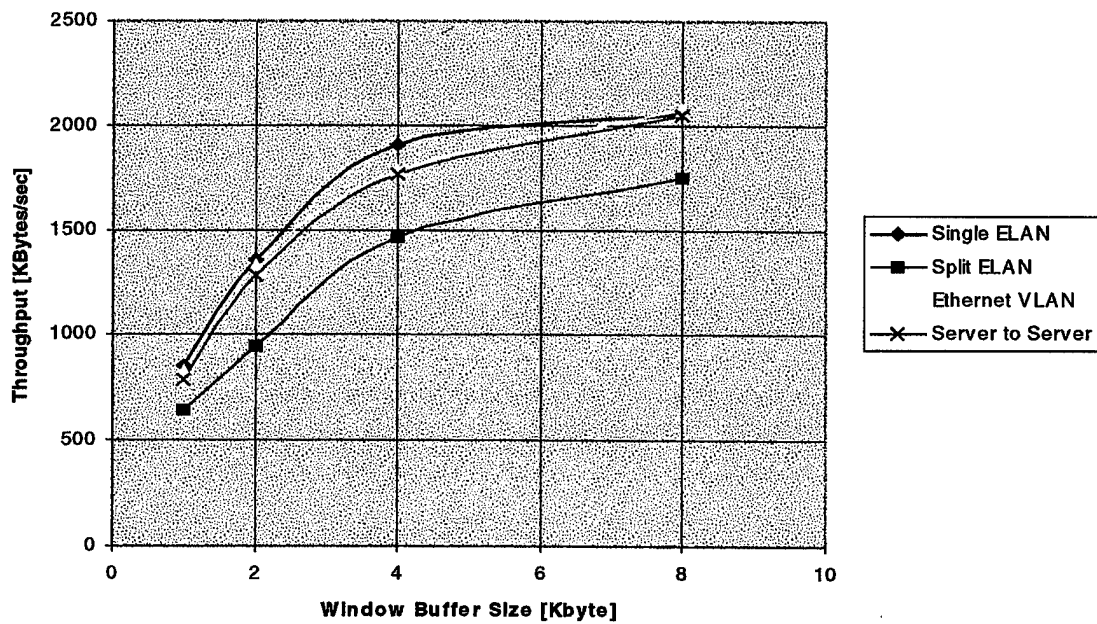
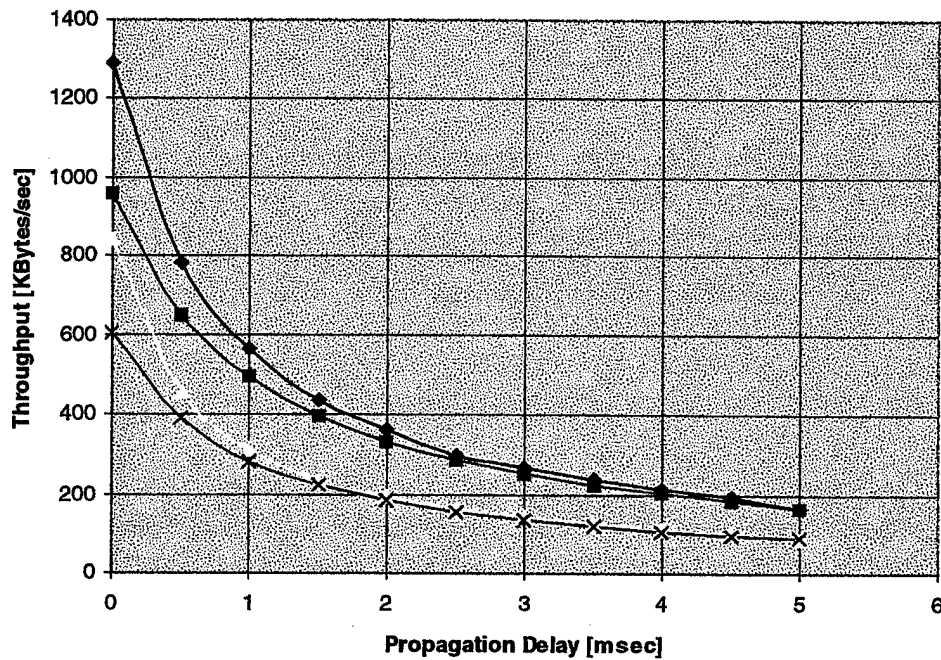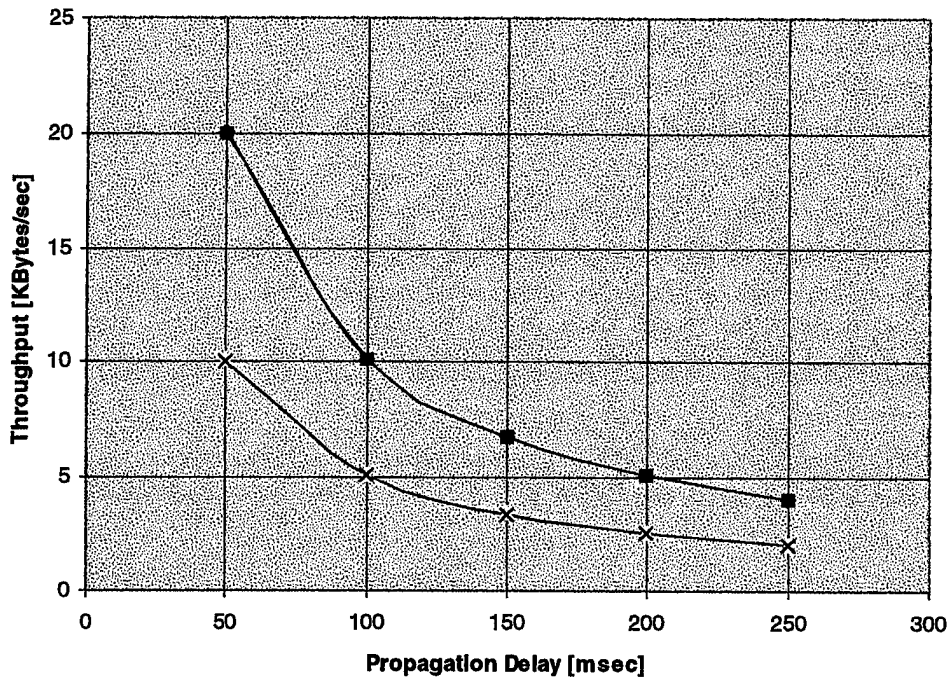**64KB data file size [Zero Propagation Delay]**

APPENDIX F. PLOTS FOR UNDERWAY SCENARIO.
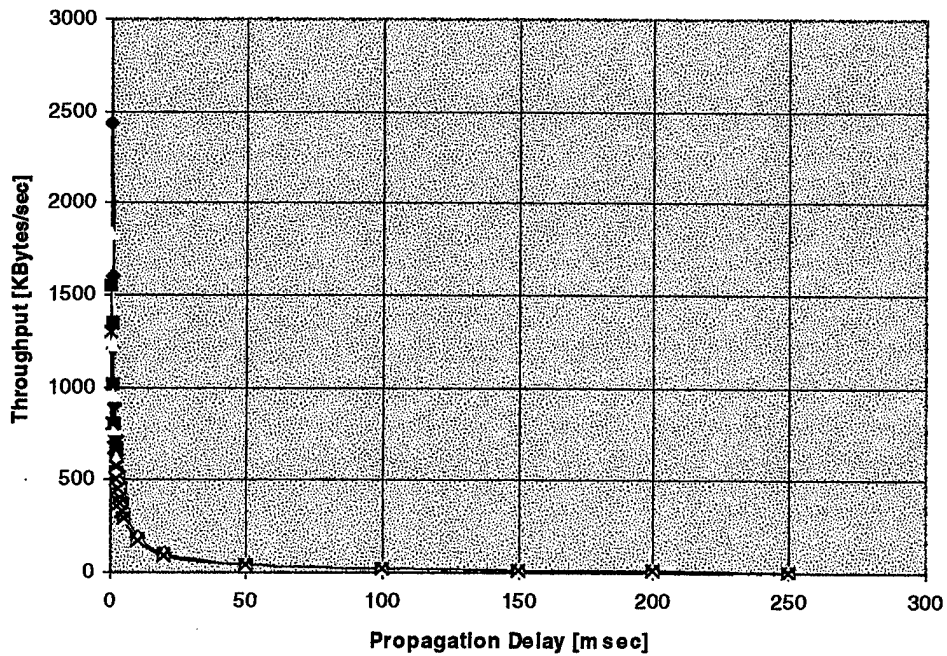
Throughput of a 1MB file with 1 and 2 KB Window

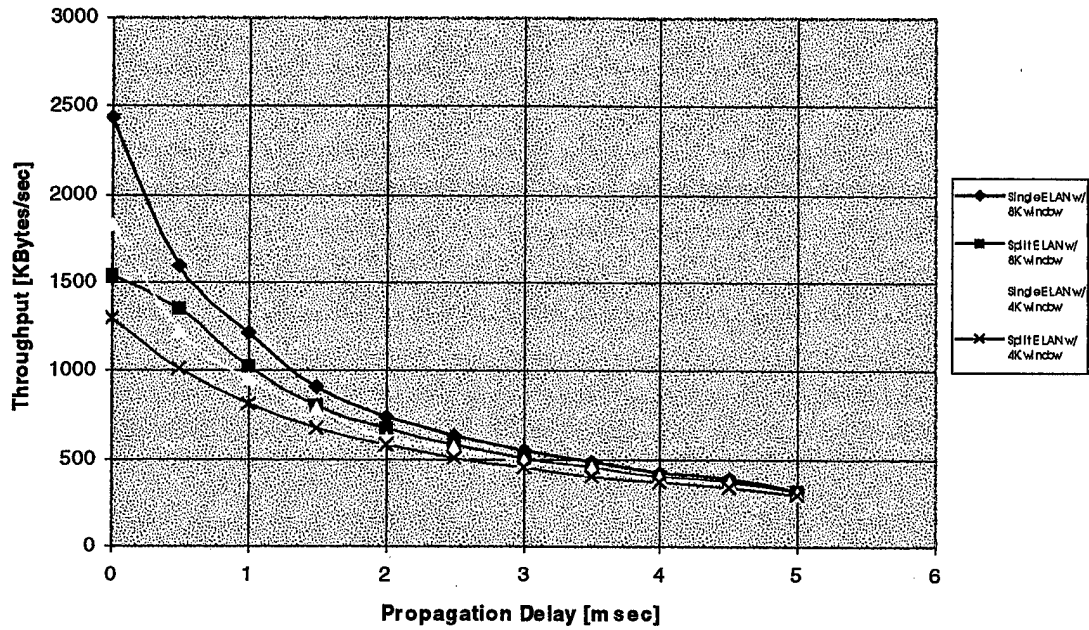**Throughput of a 1MB file with 1 and 2 KB Window**
[0 - 5 msec Propagation Delay]

Throughput of a 1MB file with 1 and 2 KB Window
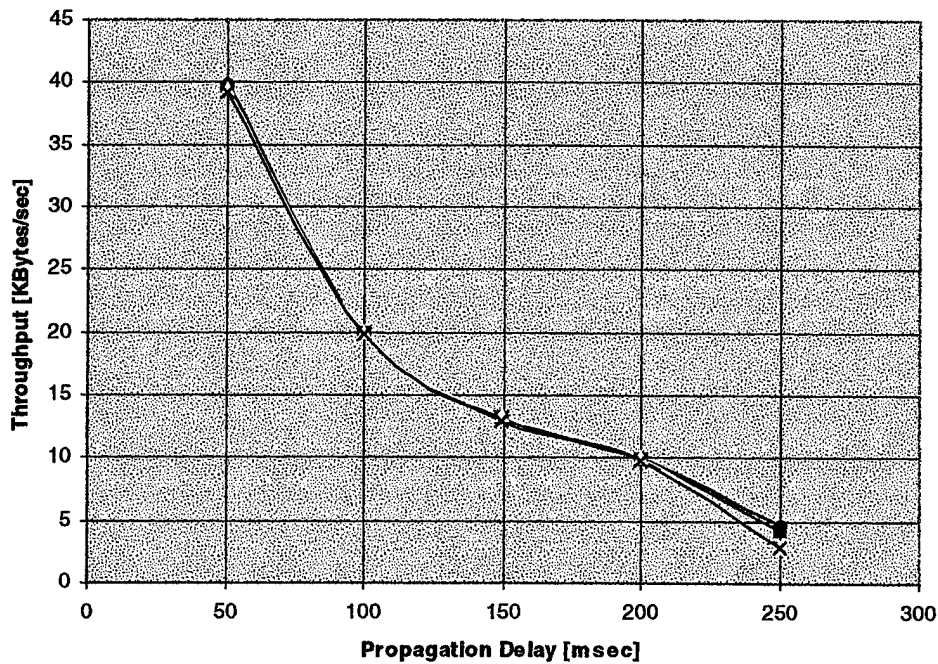### [50-250 msec Propagation Delay]
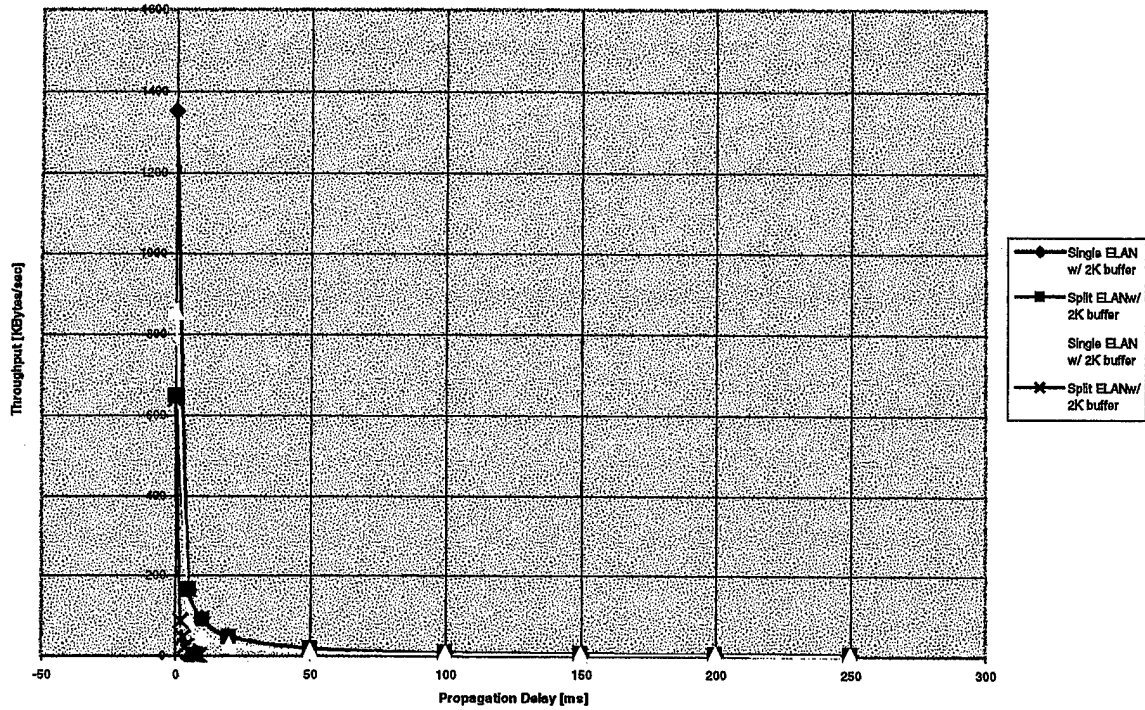

Throughput of a 1MB file with 4 and 8 KB Window

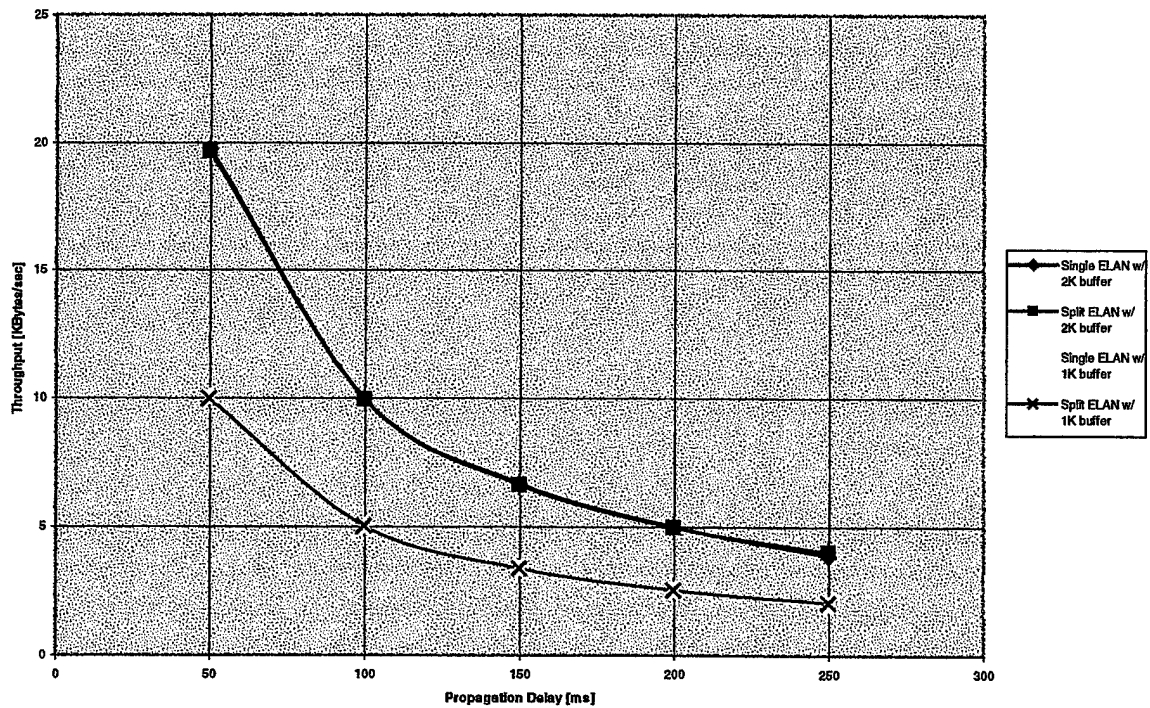**Throughput of a 1MB file with 4 and 8 KB Window**
[0 - 5 msec Propagation Delay]

Throughput of a 1MB file with 4 and 8 KB Window
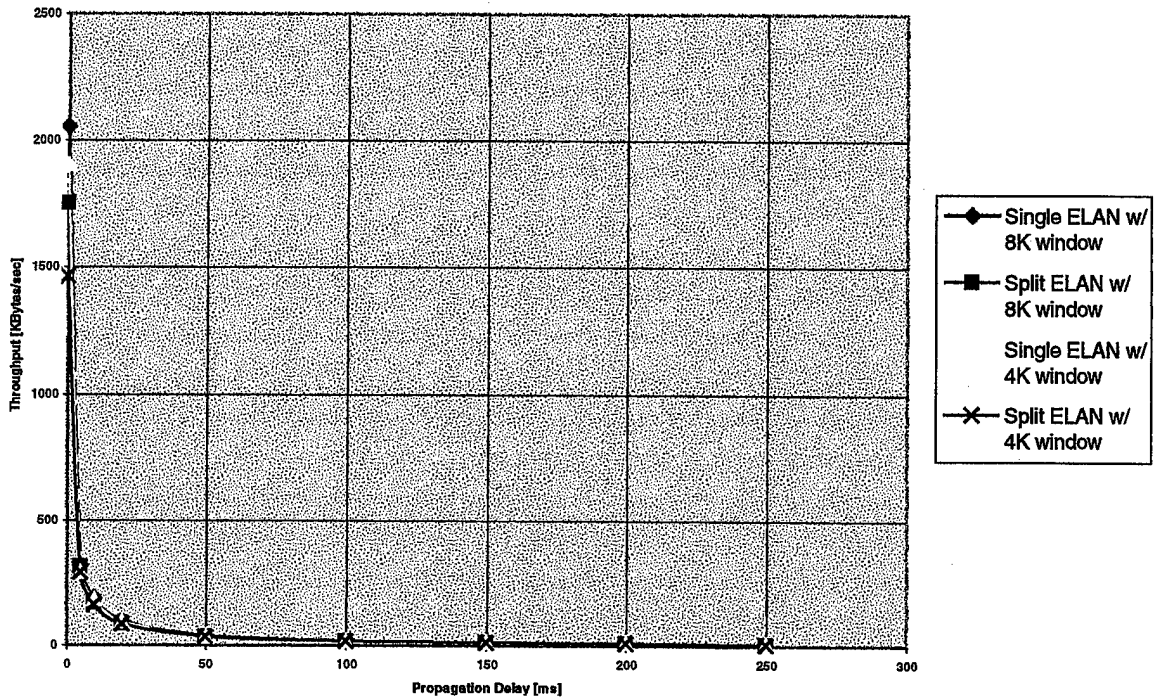**[50-250 msec Propagation Delay]**

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Throughput of a 128 KB file with 1 and 2 KB Window

Throughput of a 128 KB file with 1 and 2 KB Window
[50-250 ms Propagation Delay]

58

Throughput of a 128 KB file with 4 and 8 KB Window

Throughput of a 128 KB file with 4 and 8 KB Window
[50-250 ms Propagation Delay]

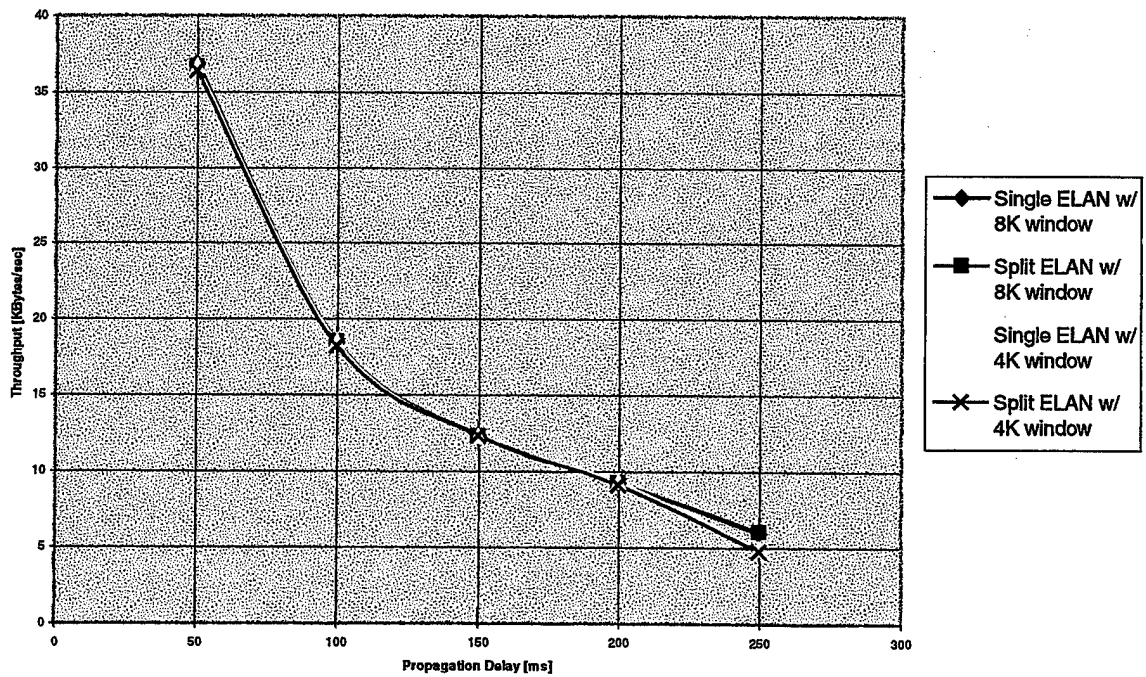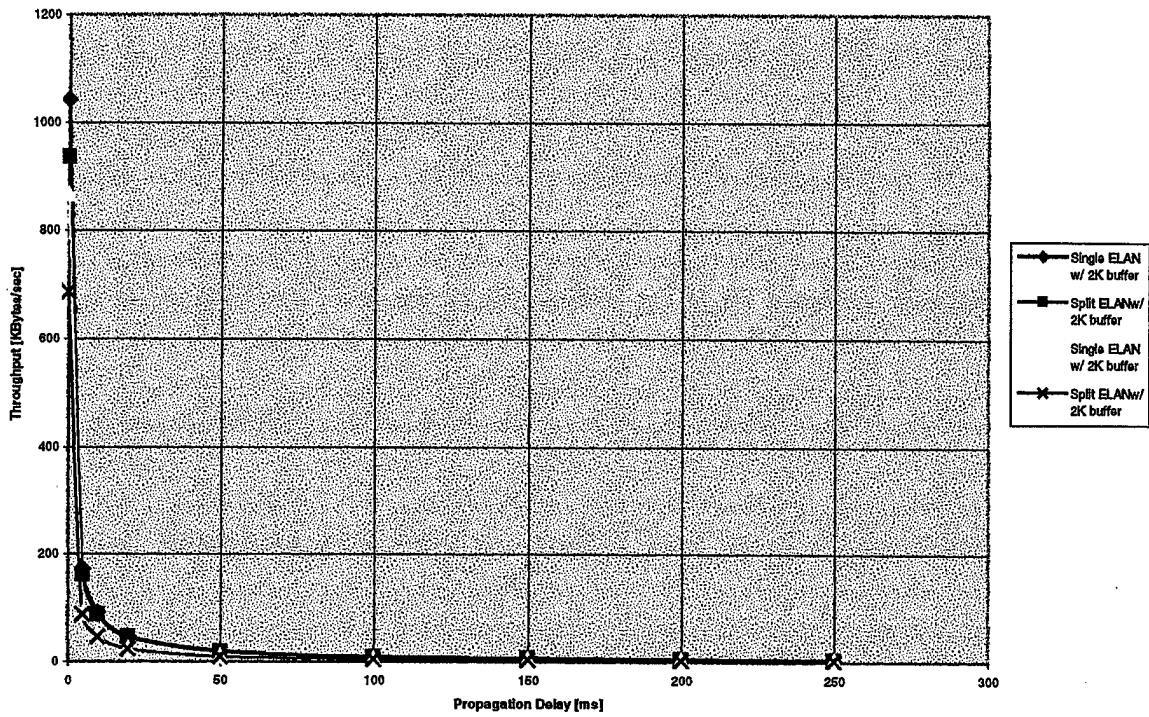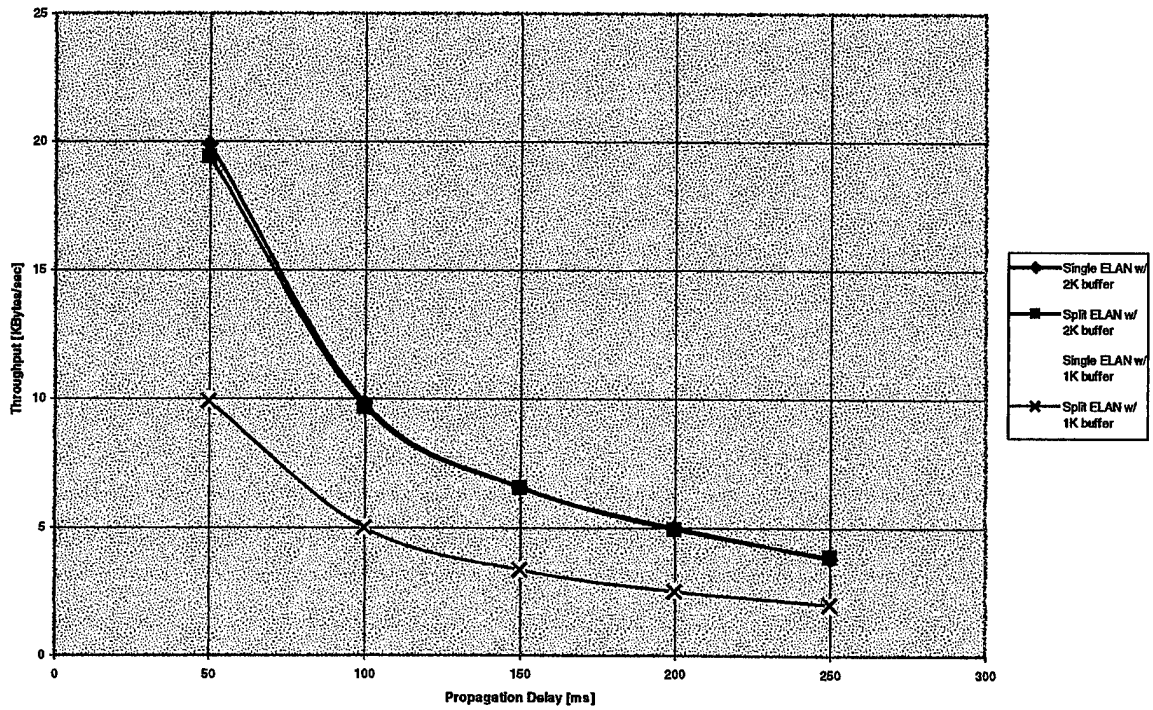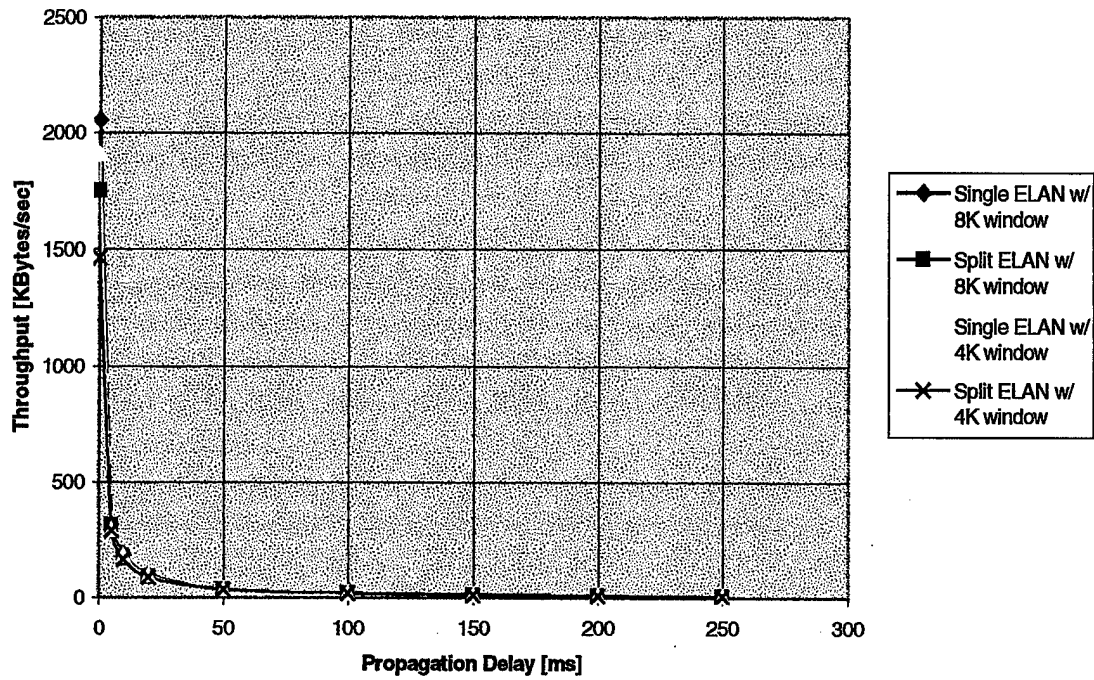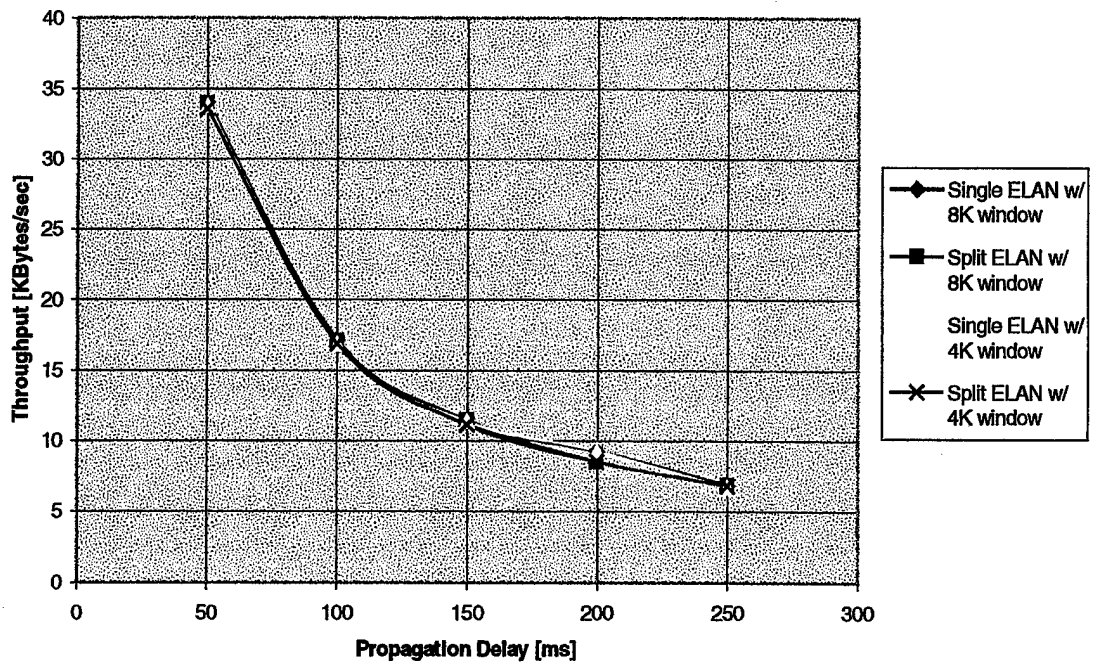**Throughput of a 64 KB file with 1 and 2 KB Window**

Throughput of a 64 KB file with 1 and 2 KB Window
[50-250 ms Propagation Delay]

Throughput of a 64 KB file with 4 and 8 KB Window

**Throughput of a 64 KB file with 4 and 8 KB Window
[50-250 ms Propagation Delay]**

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